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ABSTRACT

Described is a two-phase investigation of the electroacoustic status of hearing aids used by aurally handicapped students in the Los Angeles City Unified School District. The first phase is said to have involved field examination using portable electroacoustic equipment and the second phase to have included re-examination of 10% of the field tested aids in a laboratory setting with laboratory equipment. Results confirmed previous studies which reported large numbers of aids malfunctioning and a large number of aids worn with gain settings so low that they could not be expected to help the wearer. Among eight conclusions listed are that audiological service should include counseling and training of parents, teachers, and children in the care and use of hearing aids; that replacement parts, batteries, cords, earmolds and loaner aids should be provided as needed; and that electroacoustic evaluation of hearing aids should be made at least annually. (CL)

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The Condition of Hearing Aids Worn by Children in a Public School Program

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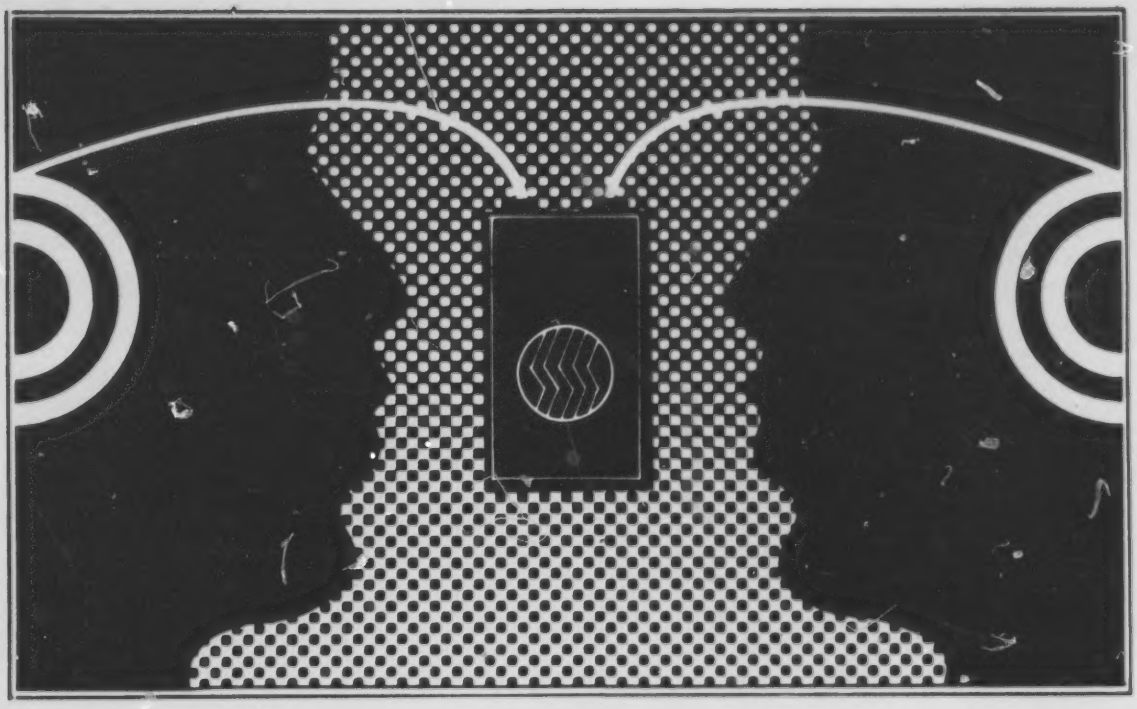

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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This report was prepared by the Bureau of Education for the Handicapped as a scientific report for the benefit of the field, however, the findings do not represent an official policy of the Bureau of Education for the Handicapped. They are intended to be of help to schools and programs for education of the deaf as they establish their own standards with respect to audiologic services.

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Foreword

During the past decade formal attention has been placed upon the use of hearing aids by hearing-impaired children in public schools. Much of this attention has focused on the ready-for-use status of hearing aids. Mark Ross, in chapter I of this report, reviews studies that have been made on malfunctioning of hearing aids. These studies show a large number of hearing aids that are not being worn, that are in poor physical condition, and that either are not functioning properly electroacoustically or have improper settings.

Hearing aids represent a sizeable personal and/or social investment both in the purchase price and in their maintenance. Hearing aids that function properly are invaluable in the education of hearing impaired children. When aids do not work adequately they are a waste of time, money, and educational efforts on the part of both the learner and the teacher.

In 1975 Congress requested that the Bureau of Education for the Handicapped conduct a study of hearing aids used in public schools. The Los Angeles City Unified School District was selected as the site to carry out this study, because it represented a large diversified target population which included special schools for the deaf, special classes for the deaf, and an integrated program in the regular schools. The district also has a system-wide audiological program. The design of the study called for a two-phase examination of the electroacoustic status of hearing aids as they are used by children in the school district. Two independent investigators performed the work of the study under the general guidelines provided by the project director. The first phase of the project was a field examination of the hearing aids through the use of portable electroacoustic test equipment. This phase is described by Fred H. Bess in chapter II. The second phase of the study was a re-examination of 10 percent of the field-tested hearing aids done in a laboratory setting with laboratory equipment. Michael R. Chial described this phase in chapter III. The laboratory phase of the study was designed to verify the field procedures. Only partially conclusive evidence can be drawn from the comparison of the two phases, inasmuch as time and money dictated that certain variables had to be excluded from the scope of the studies.

The study does corroborate previous investigations which have found large numbers of aids malfunctioning. At the same time it confirms that good and consistent in-service training programs in the care of hearing aids *will* result in better maintenance of hearing aids with respect to batteries, cords, and like accessories. Nonetheless, a large number of hearing aids tested out defective, even under fairly lenient standards. In addition, a number of aids were being worn with gain settings

so low that they could not be expected to benefit the user. The general conclusions and recommendations of the study are:

1. The original recommendation and selection of a hearing aid for a child should be made by a team of an audiologist and otologist.
2. The audiological service should include training and counseling of parents, children, and teachers in the use and care of hearing aids.
3. The hearing aid user should learn to detect malfunctions in his or her hearing aid as soon as possible.
4. The audiological service for school children should include replacement parts, batteries, cords, earmolds, and loaner aids as needed.
5. The audiological services should provide auditory training as part of the early education program for hearing aid users.
6. The audiological service should include at least an annual electroacoustic evaluation of hearing aids.
7. A systematic audiological assessment shall be a part of each hearing impaired child's individual educational plan and program.
8. The hearing aid industry and the Federal Government should explore innovative packaging designs for children's hearing aids so that they can withstand the physical strains likely to be imposed by young users.

As the project director, I wish to express my thanks to the personnel, children, and parents in the Los Angeles City Unified School District for their participation in this study.

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Dr. Thomas Behrens, Division of Personnel Preparation, OE/BEH
Dr. Joseph Rosenstein, Division of Innovation & Development, OE/BEH

The final chapter of this report contains guidelines for audiology programs for hearing-impaired children by Mark Ross and Donald R. Calvert.

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U.S. Office of Education
November 1976

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I

A Review of Studies on the Incidence of Hearing-Aid Malfunctions

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The appropriate selection of hearing aids and the supervision of the wearing of hearing aids are important aspects of the education of hard of hearing children. Hard of hearing children are auditory learners. They use their hearing as their first and primary channel for the acquisition and development of speech and language. With some variations and exceptions, they can learn from the same educational environment and procedures used with normal hearing children. To do this they must have the highest quality amplified signal that is indicated by their hearing loss. The fact that this is not the usual case is the primary subject of this chapter. Recommendations will be made which are designed to improve the utilization of hearing aids worn by all school-aged hearing-impaired children.[1]

The Performance of Hearing Aids Used in Regular Schools

In 1966, Gaeth and Lounsbury provided the first detailed examination of the performance of hearing aids used by children in regular school settings. Since that time, similar projects have essentially confirmed this first report whether they examined populations in preschool centers, special schools, or regular schools.

Gaeth and Lounsbury evaluated behavioral and physical characteristics of the hearing aids of 134 children. For 120 of the children, parent interviews were also conducted. The subjects ranged in age from 3 to 18 years and had pure-tone averages (PTAs) in the better ear of 66 dB or less in 85 percent of the cases. Sixty-three percent of the aids examined were 3 years of age or less. Only half the parents reported that the aid made some (big or little) positive difference in the child's life; the others were uncertain. The most quoted portions of the Gaeth and Lounsbury study deal with the percentage of hearing aids which were found to be functioning inadequately. Different figures are given in their report, and different figures can be used, depending upon the criteria one uses to assess "adequacy." As they put it:

> If we were to define an adequate hearing aid as one worn by the child when he came for his clinic appointment, with the volume control set at less than "full", and with all parts present and functioning, then 31 percent of the total of 134 children had adequate hearing aids. If the requirements are liberalized and the facts overlooked that the child did not wear the hearing aid when he came to the clinic, that live batteries had to be installed as necessary, and that the hearing aid was worn at full volume, then 55 percent of the hearing aids could be considered adequate. (Gaeth and Lounsbury, 1966, p. 286).

Their results indicate, whichever criteria are used, that at least half the children were not obtaining maximum assistance from the use of their hearing aids. The real situation was possibly even worse than this, since they did not report the re-

[1] The term "hearing-impaired" is used generically in this report to refer to any children with any type and degree of hearing loss (Ross and Calvert, 1967; Wilson, Ross, and Calvert, 1974).

sults of the detailed electroacoustic analysis which they performed. What we have learned subsequently about hearing aids is that an examination of the electroacoustic characteristics of hearing aids reveals many defects not apparent in a physical or behavioral examination.

The next study to provide a detailed analysis of the hearing aids worn by children in a regular school setting was reported by Zink in 1972. Over a 2-year period, he evaluated the electroacoustic performance of 195 hearing aids worn by children in regular schools. Behavioral measures are not reported. His criteria for considering the performance of a hearing aid inadequate were: (1) one increase or decrease within the frequency range of the instrument of more than 15 dB, or two or more increases or decreases of greater than 6 dB, (2) the gain and output measures were not within 6 dB of manufacturer's specifications, (3) harmonic distortion was more than 17 percent at any one frequency, and (4) gain control taper did not demonstrate adequate linearity to provide sufficient reserve gain.

In the first year, (1972) Zink found that 60 of the 103 aids evaluated (59 percent) were rejected as not meeting his criteria. Fifty-two of the 60 rejected aids were re-examined after they were presumably repaired and 18 (35 percent) were still rejected. Of the 92 aids evaluated in the second year of the study, 41 (45 percent) were unacceptable. Ten of these aids were rejected for reasons other than provided by his criteria; they displayed defective cords, receivers, gain controls, or were completely inoperative. The slight (13 percent) improvement in the performance of the aids from the first to the second year was attributed to an increased awareness toward care of the instruments by teachers, parents, and children.

In another section of his study, Zink evaluated the performance of new hearing aids as they were initially supplied to the children. Using the electroacoustic criteria as above, he found that 35 out of 75 (47 percent) were unacceptable at the end of the first year, and 7 out of 26 (27 percent) new aids were rejected after the second year. The increased acceptance rate in the second year was attributed to more selective care by the hearing aid dealers involved. As an interesting postscript to his study, Zink examined the performance of 35 used hearing aids which were donated to the children. His criterion was simply that the aids demonstrate a "usable frequency response." Of the 35 aids examined, only 3 (8 percent) were found acceptable. An electroacoustic analysis revealed such a multitude of defects that it was pointless to categorize them further. As he points out, good intentions in donating a hearing aid should not substitute for a careful examination of the aid's characteristics and usability. Otherwise, children may be harmed rather than helped by such aids.

Two other studies evaluated the performance of hearing aids worn by children enrolled primarily in public schools. Findlay and Winchester (1973) examined the hearing aids of 109 children as they were seen for routine follow-up visits in the Children's Hospital in Philadelphia. Eight of the children were below 3 years of age, 60 were 3 through 6, 27 were 7 through 10, and 14 were 11 years of age or more. The hearing aids were examined by listening, visual inspection, and electroacoustic analyses. There were problems with either the hearing aid or the earmold in 65 of the 109 aids. Problems with the aids noted were inadequate gain, excessive harmonic distortion, electronic malfunctions (static, noise, intermittency, etc.), battery defects, and damage to either casing controls, cords, tubing, or receiver. Earmold problems included improper fit in ear, poor coupling between mold and receiver, cracked or broken mold, and cerumen blockage of sound port. More defects

and malfunctions were noted with the preschool population's aids than with those of the older children. Twenty-three of the 109 children were seen for a second visit within a 6-month period with mixed results. Some had problems the second time but none the first, some had problems both times, and some had their initial problems corrected by the time of the second visit. These observations demonstrate the necessity for an ongoing hearing aid monitoring program, because of the rapidity with which negative alterations in performance are possible.

At the University of Cincinnati Medical Center, Schell (1975) evaluated between 60 and 75 hearing aids each year for 2 years by means of a visual inspection, listening, and electroacoustic analysis. The aids belonged to children enrolled in the Cincinnati Public Schools. Her results indicate that about 45 percent of the aids needed major repairs for such problems as excessive distortion, reduced gain, frequency response, while a few were totally dead. About 12 percent demonstrated minor problems, such as with a broken cord or a poor tube. The total number of malfunctions exceeded 50 percent which is comparable to the previous studies reviewed.

Hearing-Aid Performance in Special Programs

One expects that when a child is enrolled in a "special" program for hearing impaired children that the incidence of malfunctioning hearing aids would be greatly reduced because of the sensitivity to potential hearing aid problems by the professionals in the program. The published research supports this expectation only in part. In programs in which the audiological component is stressed and audiologists are physically present and administratively tied to the program, then such expectations can be fulfilled (Hanners, 1973). However, when one audiologist is expected to serve the audiological needs of several hundred children, sometimes all he or she can do is call attention to the problem and hope for its eventual amelioration. Two studies falling in this latter category have been published.

Northern, et al. (1972) identified 174 children with hearing aids in a residential school. Notices had been sent to parents asking that they ensure that their child's hearing aid be sent to the school on a specific day for evaluation of its performance. Thirty-six of the aids were not available on the day of the evaluation, which would lead one to expect that these hearing aids played hardly any significant role in the child's life. Of the 138 aids examined, only 43 (31 percent) were found to be in satisfactory working condition. The most common deficiencies noted were broken or poorly fitting earmolds; broken or faulty receivers, switches, battery contacts, cords, and batteries; and excessive noise and distortion. At that time, the school had only part-time audiological services available.

Porter (1973) evaluated 113 children at the Kansas School for the Deaf who were brought to the clinic directly from the classroom. He felt that the results of his evaluation would thereby provide a reasonably accurate picture of the conditions of the hearing aids as they were used in classrooms. Of the 113 children, 31 were not using individual hearing aids, though aids had either been recommended or repair of existing aids suggested. A total of 82 aids were available for the study. The hearing aids were examined through visual, listening, and electroacoustic analyses. The results, as Porter points out, "can only be described as disheartening, although not entirely unexpected. Forty-two (51 percent) of these aids were judged

not to be in adequate operating condition at the time of the evaluation." Many of the problems were easily observable and some readily correctible with a routine inspection procedure. For example, 10 of the aids had dead batteries and 10 of the children had inadequate earmolds. Problems with cords, switches, volume controls, and like components were also noted. In other aids there were marked changes in the frequency response, or excessive distortion. A separate analysis of the incidence of faulty functioning for the day students' aids as contrasted with the residential students' aids revealed that the same percentage of malfunctions occurred. The expectation that the greater parent involvement with day students would reduce the number of hearing aid malfunctions was not fulfilled.

The topic of hearing-aid malfunctions provides a good example of how an applied research project can lead to a program modification for the betterment of children. In 1972, Coleman reported a study regarding hearing aid stability in a preschool program located in the Bill Wilkerson Center in Nashville. He evaluated 25 hearing aids over a 9-month period in 2-week intervals and found results similar to those observed in other studies, namely, that about 50 percent of the aids were either not functioning or functioning improperly. Large frequency response changes occurred in about 30 percent of the aids, with high distortion products characterizing one-fourth of the aids (Coleman, 1972). The second half of this project involved a training program in which parents, graduate students, and staff were taught to troubleshoot hearing aids on a daily basis. At the conclusion of the training program, the incidence of faulty functioning was reduced to about 20 percent of the aids tested. In a later report, Coleman wrote somewhat pessimistically concerning the effectiveness of the twice-weekly monitoring program instituted during the second part of the study (Coleman, 1975). The basis of his discouragement was obvious: in an "acoustic" preschool, with a commitment to maximizing use of residual hearing, with adequate staff and facilities, breakdown in hearing aid performance still occurred on a regular basis. However, in the same facility, Hanners and Sitton (1975) instituted a daily hearing-aid monitoring program with reported positive results. A hearing aid monitor kit was assembled, a testing protocol was established, a formal parent training program was developed which included sound-slide media and booklets, and a routine, daily monitoring of hearing aid performance accomplished. On the basis of the reduced malfunctions of hearing aids, the condition of the children's aids, and the positive reactions of the teachers, the program was deemed a success.

Discussion

The agreement among all the projects which have been reviewed by this author indicates that the incidence of faulty hearing-aid operation is too great to be purely coincidental. On numerous occasions, many educational audiologists have consulted and conferred with industry representatives, encouraging them to attempt to build "a child-proof" hearing aid. Some companies have been sympathetic and have attempted to respond to such pleas. However, the healthy, normally rambunctious child has defeated our best efforts to date. Although one would hope that it is possible to improve further the durability of conventional hearing aids, the children we deal with are apt to be a lot tougher than the toughest of our instru-

ments. Solutions to our problems—how to keep a child's hearing aid working in an optimal fashion—will have to be sought through other approaches.

Actually, the deplorable litany of hearing aid malfunctions described above presents an optimistic picture of the real situation faced by children wearing aids in school. The hearing-aid user is faced with a number of other relevant factors which reduce the fidelity of the amplified speech signal received through a hearing aid. Two factors, the negative effects of classroom acoustics, and the necessity for individualizing the electroacoustic characteristics for a particular child have been identified by the author elsewhere (Ross, 1973, 1975, 1976). The advantages of binaural amplification for most children, supported by a number of recent research projects, is another relevant consideration (Fisher, 1964; Kuyper and deBoer, 1969; MacKeith and Coles, 1971; Ross, et al., 1974; Yonovitz and Campbell, 1975; Nabelek and Pickett, 1974; Dermody and Byrne, 1975).

In summary, the obstacles preventing a hearing impaired child from obtaining the maximum benefit from amplified sound are:

1. many hearing impaired children who can potentially benefit to some degree from the use of a hearing aid do not have one;
2. a significant percentage of children who do possess hearing aids do not wear them;
3. the hearing aids of approximately 50 percent of the children who do wear them are either inoperable or malfunctioning on any given day;
4. the acoustical conditions pertaining in the average classroom virtually preclude the reception of an adequate speech signal;
5. the electroacoustic characteristics of a perfectly functioning hearing aid must still be modified to some extent to reflect the individualized pattern of hearing impairments if the maximum potential benefit is to be received;
6. the evidence supporting binaural amplification for most hearing impaired individuals is not uniformly reflected in actual practice;
7. perhaps the most important reason of all, the widespread ignorance among professionals and lay people of what amplified sound is all about, and their apparent reluctance to correct the situation.

Indeed sufficient sophistication exists for many of these professionals for them to realize the extent and implications of their own ignorance. Such a knowledge, of course, is the basic prerequisite for progress. Coleman (1975) provides some disturbing insights which support these harsh, but necessary comments. He found that reactions to news that 50 percent of children's hearing aids were not operating adequately on any given day ranged from expressions of amused chagrin, to pseudo-scientific questions regarding the educational impact of inadequate or absent amplification, to attitudes of hopeless resignation.

Recommendations

There was one common recommendation made in all the studies which reviewed the performance of hearing aids worn by children: the need for the informed involvement of all parents and professionals in the hearing aid monitoring process. It is unlikely in the foreseeable future that the stability and durability of hearing

aids will be sufficiently developed to obviate the need for this involvement. Whatever the technical impediments that preclude the manufacture of the "child-proof" hearing aid, the economic motivation is simply not there: children represent a minor proportion of the total hearing-aid market, from 10,000 to 15,000 hearing-aid sales annually. If we accept the notion that hearing-impaired children require the best functioning hearing aid for their optimal development of communication skills, then we must accept the commitment to implement an ongoing, intensive program of hearing-aid monitoring wherever hearing impaired children are being educated in school and at home.

The presently fragmented methods of delivering educational and clinical services to hearing-impaired children make this a difficult goal to realize. Responsibility for supervising utility of hearing aids is diffusely distributed among parents, regular teachers, special teachers, speech pathologists in the public schools, independent speech and hearing clinics, and in some localities, educational audiologists. Educational audiologists possess the greatest degree of professional expertise in the area of hearing aids. In a comprehensive auditory-based program for hearing impaired children, hearing-aid monitoring is only one component; nevertheless some way must be found to ensure that the skills of the educational audiologist are a functional part of the child's routine school program.

A detailed examination of possible service delivery models which include the central role of the educational audiologist is beyond the scope of this paper. We have some examples in some localities in city and county-wide educational programs which employ educational audiologists to oversee the recommendation and usage of amplification for the hearing impaired children. This is in addition to their responsibilities in supervising, and perhaps conducting, the hearing screening program. Test facilities are an integral component of such a program (with mobile vans an exciting possibility in the more rural areas). Unfortunately, not all State Education Agencies have certification requirements for educational audiologists, so that even if an educational system wanted to employ such persons, there is no legal way for them to do so. The training of audiologists to meet the new challenge of providing audiological necessities for the hard of hearing child in the regular school is still lagging at the university level. There is, however, a rising awareness of the hard of hearing child's needs and a new commitment by training centers to train audiologists to meet this new challenge. What is most needed now is an awareness on the State level of the potential value of educational audiologists, and an energetic effort to devise educational models and certification requirements so that hearing impaired children might have the benefit of the best amplification and educational programs possible.

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II

Condition of Hearing Aids Worn by Children in a Public School Setting

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The hearing aid represents the hearing handicapped individual's primary link to an acoustically dominated society. In order to insure that a hearing impaired child gains the maximum possible educational benefit through audition it is essential that hearing aids perform satisfactorily on a continual basis. Unfortunately, several studies (Gaeth and Lounsbury, 1966; Zink, 1969; and Coleman, 1972) have reported that the performance of children's hearing aids used in the classroom is frequently inadequate and unreliable. These studies have estimated that as many as 40–50 percent of children's hearing aids in the educational setting perform unsatisfactorily.

The purpose of this study is to contribute further information relative to the characteristics of children's hearing aids as used in a large metropolitan school system.

Methods and Procedures

Description of Public School Program

The sample of hearing aids was taken from the program for the hearing impaired within the special education division of the Los Angeles Unified School District. This large, diversified educational program provides services to over 1,000 moderately and severely hearing-impaired children in the metropolitan Los Angeles area. The program is divided into three basic units. One division serves those children who are in need of special schools and/or classes. Self-contained classrooms for preschool, elementary, secondary, and postsecondary levels are offered. The second division is designed to provide integration for hearing-impaired children within the regular elementary and secondary schools. In this setting, children receive assistance from a resource-room teacher of the hearing impaired while attending classes and other school activities with students of normal hearing. The third division allows the hearing-impaired child to remain within his or her own neighborhood school while an itinerant teacher provides specialized tutorial assistance two or three times each week.

A staff of educational audiologists provides continued audiological management to the children in each program. For the most part, services consist of hearing assessments, teacher-parent-administration consultation, classroom consultation for amplification equipment, monitoring of children's hearing aids, and in-service instruction for classroom teachers of the hearing impaired. Pertinent to this study is the program for hearing-aid management which began in September 1975. Inservice training is provided for the teachers of the hearing impaired to establish daily monitoring programs within the school system. Teachers are provided with battery testers and are taught to troubleshoot typical hearing aid problems. Parents are also provided with information on the care and maintenance of their children's hearing aids. Samples of the forms used in the school monitoring program are shown in appendix A.

Sampling Method and Procedures

The goal of this study was to assess 150 hearing aids randomly selected from a stratified sample of hearing aid users in the Los Angeles system. Toward this end, release forms (appendix B) were distributed to 158 parents whose hearing-impaired children attended 18 different Los Angeles schools. The parents of 136 children consented to provide their children's hearing aids for study. Many of the pupils wore binaural systems. From this group, 150 hearing aids were initially selected for evaluation.

The hearing aids were examined during the week of February 2–5, 1976. The condition of each aid was inspected first for any obvious problems or physical damage, such as occluded earmolds, bad tubing, cracked cases or receivers, and frayed cords. Electroacoustic measurements were then obtained for each hearing aid. The instruments were analyzed at five different central school locations. If only a few hearing aids were selected from a specific school, teachers or assistants brought the children's instruments to a central location. The hearing aids used by 103 children were analyzed; 18 wore binaural systems. The total examined was 121.

It is important to note that 37 children who initially were volunteered to participate in this study either did not wear their hearing aid on the day of the analysis or failed to come to school. Thus, in order to obtain a larger sampling of hearing aids, it was necessary to examine more binaural systems than was anticipated. Sixty-six, or 54 percent of the instruments were head-worn (ear level); 55, or 45 percent were body-worn; six of the body hearing aids utilized a y-cord arrangement.

Apparatus and Procedures to Establish Electroacoustic Measurements

Apparatus

An HC 2000 Phonic Ear Acoustic Computer, associated with a prototype Phonic Ear strip chart recorder (HC 2200), was used for the electroacoustic analysis of the hearing aids. This apparatus provided sweep frequency output response characteristics as well as total, 2nd and 3rd harmonic distortion in percent for input levels varying from 50–100 dB sound pressure level (SPL). The test microphone and chamber of the acoustic computer were checked on a periodic basis each day. Calibration of the microphone (High Dynamic Telectret) was checked using a 1′ Bruel and Kjaer (4230) calibrator which emits a 1000 H_z pure tone at 94 dB SPL. An external calibration potentiometer was adjusted until a 94 dB signal was obtained on the dB SPL digital display.

The SPL within the chamber of the acoustic computer was examined by placing the regulator microphone perpendicular to the sound source about ¼″ from the test microphone. An 80 dB SPL input was then introduced to the chamber and the calibration potentiometer adjusted until 80 dB was obtained on the dB SPL digital display. Throughout the experiment, calibration was found to remain stable.

Procedures

Each aid was analyzed under two different conditions. First, measurements were taken at an "as worn" setting. That is, the hearing aid was examined at the same

volume setting and battery the child was using at the time. Second, a series of "standard" measures were obtained, always utilizing a fresh battery.

Each aid was placed in the chamber of the acoustic computer. The output of each aid's receiver was coupled to a 2–cc coupler (Breul and Kjaer—dB 0138) and microphone. A ¾" number 15 size tubing was always used in association with the ear-level instruments. The amplified output was then displayed and printed out by the prototype strip chart recorder.

For the "as worn" setting, a 70 dB SPL input signal as recommended by Rintelmann and Schumaier (1973) was employed for a sweep frequency and total harmonic distortion response. The "standard" setting measures consisted of acoustic gain, saturation output, total harmonic distortion, and a basic frequency response. The acoustic gain of the hearing aid was determined with the volume control at its maximum (full-on) position using an input of 50 dB SPL. Saturation output was measured with the volume control at maximum position and using an input of 90 dB SPL. Total harmonic distortion was made again with the volume control at maximum and employing an input signal of 75 dB SPL. Finally, a basic frequency response was measured by using a 1000 Hz input at 60 dB and adjusting the gain control until 100 dB SPL had been achieved within the 2–cc coupler.

Results

Physical Condition of Hearing Aids

Twenty-seven percent of the 121 hearing aids were judged unsatisfactory in at least one category of physical wear. The percentage of hearing aids considered inadequate in each of these categories is displayed graphically in Figure 1. Thirty percent of the ear-level instruments were rated as having poor tubing. Five percent of the total number of hearing aids exhibited either broken or cracked cases, and 8 percent of the earmolds were found occluded and/or cracked. Finally, of the body-worn hearing aids, 9 percent had broken and/or cracked receivers; 14 percent of the cords were considered unsatisfactory. These findings are in agreement with Peck (1969) who found that one-third of 24 hearing aids he examined were inadequate for classroom use.

The batteries of all hearing aids were examined for voltage output. If the voltage reading was less than the fully specified rating for a given cell, batteries were considered weak. Using this criteria, 15 percent of the hearing aids were not at full strength. The findings were better than expected. Coleman in 1972 reported that 40 percent of the batteries from 25 hearing aids worn by hearing-impaired children failed to attain at least 75 percent of the rated voltage. Two factors may provide an explanation for the improved results obtained in the present study. First, recall that release forms were distributed to the parents of all prospective participants. This may have resulted in parents' making a conscious effort to provide a fully-charged battery on the day of the test. However, the parents did not know exactly when the aid was to be tested. Another factor may be the hearing aid monitoring program initiated by the audiology staff in September 1975.

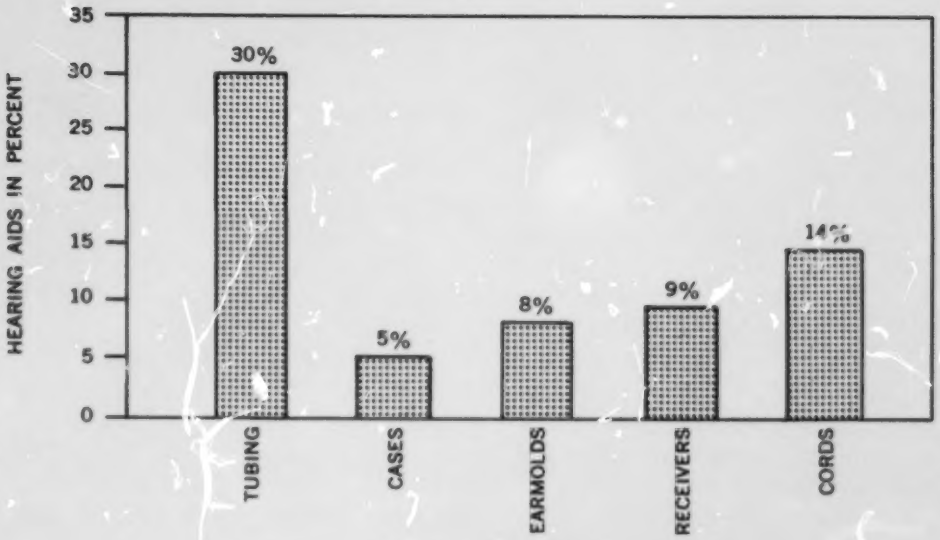

Figure 1.—Percentage of hearing aids exhibiting faulty components.

Electroacoustic Analysis of Hearing Aids

The acoustic data for hearing aids were analyzed, first, by examining group total harmonic distortion (THD); second, by determining the acoustic gain, and third, by comparing a sample of hearing aids and their acoustic measurements to manufacturer's specifications.

Total harmonic distortion for the "as worn" and "standard" conditions were computed for 500, 700, and 900 Hz. The average THD for the three frequencies was also calculated. The number of hearing aids in percent exhibiting an average THD of $\geq$10 percent, $\geq$20 percent, $\geq$30 percent and $\geq$40 percent is displayed in Figure 2. As expected, when a 75 dB input is used with the volume control at maximum, higher THD measures were obtained than was found in the "as worn" condition. For both conditions, however, high average THD levels were observed. Seventy-four percent of the hearing aids exhibited average THD of $\geq$10 percent for the "standard" measure while 27 percent of the hearing aids in the "as worn" condition showed THD of $\geq$10 percent.

Significant is the large number of hearing aids which exhibited average THD in excess of 20, 30, and 40 percent for the "standard" and "as worn" conditions. For example, with the "standard" measure, 48 percent of the hearing aids exceeded 20 percent THD, 24 percent were in excess of 30 percent THD, and 14 percent produced distortion greater than 40 percent. In the "as worn" condition 10 percent of the hearing aids distorted greated than 20 percent, 7 percent exceeded 30 percent THD, and 5 percent was greater than 40 percent THD.

A more detailed summary of the obtained THD levels is presented in Table 1. This table presents the percentage of hearing aids exhibiting four different degrees of THD at 500, 700, 900 Hz and the three-frequency average for both the "as worn" and "standard" conditions. Again the large number of aids producing distortion in excess of 20 percent is evidenced.

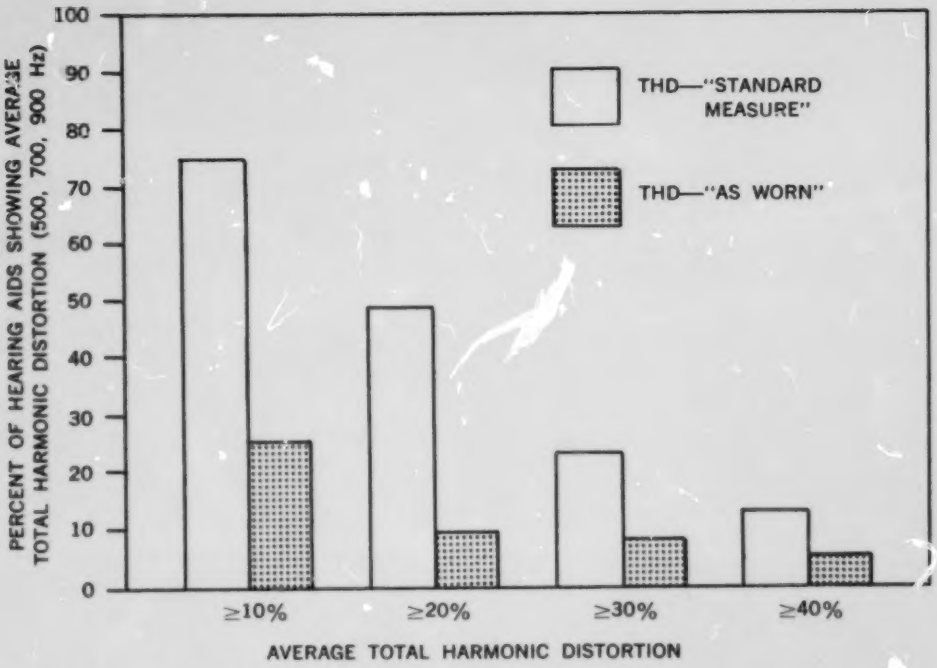

Figure 2.—Number of hearing aids in percent showing average THD ≥10 percent, ≥20 percent, ≥30 percent, ≥40 percent.

Table 1.—Percentage of hearing aids exhibiting degrees of THD at 500, 700, and 900 Hz and a three-frequency average for both "as worn" and "standard" measure conditions.

Amount or THD	THD (in %) as worn				THD (in %) standard measure			
	500 Hz	700 Hz	900 Hz	Aver.	500 Hz	700 Hz	900 Hz	Aver.
≥10%	31	23	21	27	64	73	67	74
≥20%	14	10	9	10	50	50	35	48
≥30%	11	8	7	7	31	28	16	24
≥40%	8	6	4	6	19	15	12	14

Acoustic Gain

The acoustic gain at 500, 1000, and 2000 Hz was averaged for the "as worn" and "standard" conditions. It is of interest to note that for most children the acoustic gain was considerably less in the "as worn" setting than at the "standard" setting. For example, the mean acoustic gain for the 121 hearing aids in the "as worn" condition was only 38 dB, while the mean gain for the "standard" measure was 59 dB—an average difference of 21 dB.

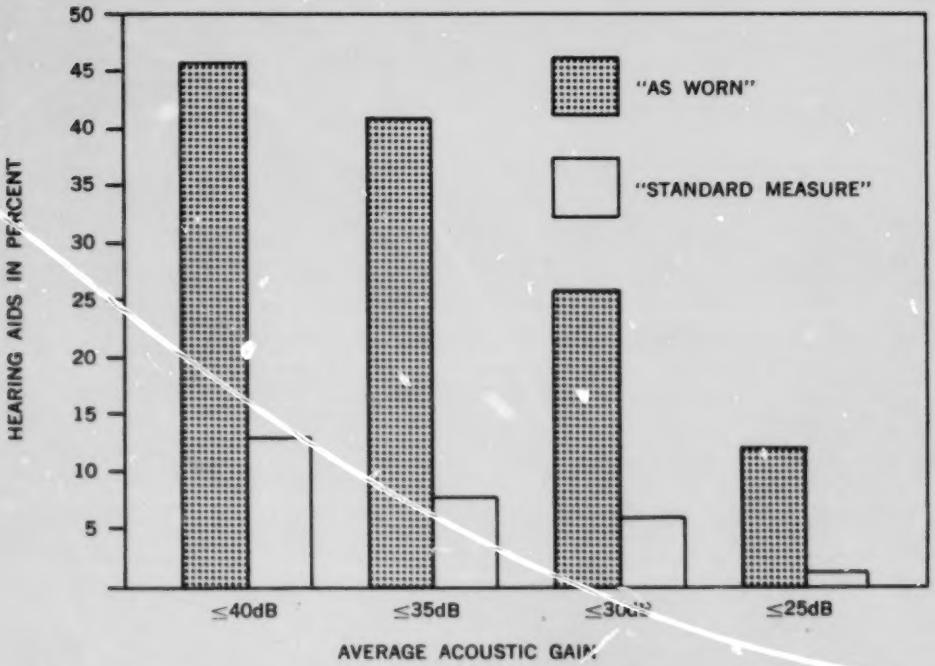

Figure 3.—Percentage of hearing aids producing gain value 40 dB or less.

Figure 3 illustrates in more detail the differences which existed between the two conditions. This figure displays the percentage of hearing aids within each condition producing specified acoustic gain values. Apparent is the number of hearing aids producing low-gain values at the "as worn" setting. Over 40 percent of the hearing aids produced gain levels of 40 dB or less, while 27 percent produced gain values of $\geq$30 dB. Additionally, the small percentage of aids with acoustic-gain values of $\leq$40 dB using a "standard" measure implies that most instruments under this condition produced values in excess of 40 dB.

The acoustic-gain values in the "as worn" setting suggest that many of the children with severe-to-profound hearing losses were wearing their hearing aids at volume control settings insufficient to compensate for the hearing impairment. To examine this possibility more closely, 35 of the children's hearing aids were randomly selected from the pool and their "as worn" gain values were examined in relation to the hearing loss. Twenty of the losses were classified as profound ($\geq$91dB), ten were severe (71-90 dB), and five fell into the moderate-severe catagory (55–70 dB). For those children with profound hearing losses, 45 percent of the hearing aids produced gain levels of 35 dB or less. Fifty percent of the hearing aids yielded gain values of $\leq$35 dB for the severe hearing loss category and 5 percent for the moderate-severe losses. These findings are similar to the results of Gaeth and Lounsbury (1956) who reported that gain was inadequate for 52 percent of the hearing-impaired children examined. Other investigators have similarly reported that individuals tend to use hearing aids at low gain levels (Brooks, 1973; Martin, 1973; Skalka and Moore, 1973; and Bryne and Fifield, 1974).

Comparison to Manufacturers' Specifications

Thirty-five, or 29 percent of the hearing aids were randomly chosen from the pool of 121, and selected acoustic measurements were compared to the manufacturers' specifications. The electroacoustic measurements chosen for study included acoustic gain, saturation output, and basic frequency response. Tolerance limits suggested in the draft proposal of the **American National Standard For Specification of Hearing Aid Characteristics** (S3.22, 1975) were modified and used to determine whether a selected aid agreed with the manufacturers' published specifications.

For acoustic gain, a tolerance of ±5 dB of the manufacturers' specified value for the average of frequencies 500, 1000, and 2000 Hz was considered acceptable. For saturation output, allowable tolerance was examined first for peak value at 1000 Hz and second for an average of 500, 1000, and 2000 Hz. In both instances allowable tolerance was any value falling within ±4 dB of the manufacturers' specified amount. To establish the tolerance limits for the basic frequency response curve the following procedure was employed:

From the manufacturers' published frequency curve the average for response values 1000, 1600, and 2500 Hz was determined. Twenty decibels was then subtracted from this amount, and a horizontal line was drawn parallel to the abscissa so that it intersected at both the high and low frequency ends of the response curve. A ±4 dB tolerance was used at the low band for frequencies up to 2000 Hz and ±6 dB at the high band for frequencies between 2000 and 4000 Hz. The upper and lower limits for the entire response curve could then be calculated. Additionally, a horizontal allowance of ± 10 percent in frequency was permitted.

The percentage of hearing aids failing to agree with manufacturers' specifications for the different acoustic measures is summarized in Table 2. Regardless of the measure, 25 percent or more of the hearing aids failed to meet manufacturers' specifications. More importantly, 80 percent of the instruments did not agree with the published specifications for frequency response. While it is apparent that many of the hearing aids were not compatible with the manufacturers' data, interpretation of these findings must be made with some caution. First, not all manufacturing companies specify how an acoustic measure was determined, and under such conditions we assumed that procedures suggested by the Hearing Aid Industrial Conference (HAIC) were employed. Second, hearing aid models are constantly being modified and refined. Consequently, the same model may exhibit some minor changes in electroacoustic specifications over a period of time. Given the time limitations of the present investigation, it was not possible to obtain the specification information supplied at the time of manufacture of the hearing aids evaluated

Table 2.—Percentage of hearing aids failing to agree with manufacturers' specifications for selected electroacoustic measurements (N = 35).

Acoustic gain	Saturation output		Frequency response
	1000 Hz	average	
38%	25%	30%	80%

in this study. Nonetheless, this writer is impressed with the number of aids not meeting specifications, when available.

Discussion

The results of this study confirm previous reports that a large percentage of children's hearing aids in the public school setting do not provide adequate performance. Irrespective of the measure analyzed, a minimum of 25–30 percent of the hearing aids were found to perform unsatisfactorily.

The physical condition of the hearing aids was judged inadequate 27 percent of the time. This finding is somewhat surprising in view of the audiologic hearing-aid monitoring program in effect in the school that cooperated in this study. Perhaps the monitoring program needs to place more emphasis on the care and maintenance of hearing aid components. Only 15 percent of the hearing-aid batteries were not at full strength. This result represents an improvement over previous findings (Coleman, 1972) and is most probably due to the hearing-aid monitoring programs provided by the audiologic staff.

The data obtained on harmonic distortion are difficult to interpret. Not only is a standardized measurement unavailable, it is not yet clear what effects distortion has on the hearing aid user. Some research, however, has suggested that harmonic distortion in excess of 20 percent causes degradation of speech intelligibility (Harris, Haines, Kelsey, et al., 1961). In the present study, 48 percent of the hearing aids exceeded 20 percent THD for the "standard" measure. The large number of hearing aids showing high distortion levels may be due partially to our use of a 75 dB input. Such a level approximates the point of saturation for hearing aids, thus accounting for higher distortion values.

Nevertheless, the nonlinear distortion values obtained in this study were greater than one expected to find in the average hearing aid. Lotterman and Kasten (1967) observed harmonic distortion as a function of gain-control rotation in 35 clinic stock instruments using a 70 dB SPL input. At the maximum gain-control setting they found that the nonlinear distortion for body-worn hearing aids (N–17) averaged 21 percent at frequencies 500, 700, and 900 Hz; ear level instruments averaged 9.6 percent. The present study observed considerably higher distortion values using similar measurement procedures.

The "as worn" measure of harmonic distortion may provide a more realistic indicator of the distortion affecting the hearing aid user. Ten percent of the instruments exceeded 20 percent THD. However, over 40 percent of the children used volume settings which produced gain values of 35 dB or less. Such mild gain settings most likely resulted in a lowering of the overall THD values in this study.

A significant finding of this investigation was the acoustic-gain values obtained in the "as worn" condition. Many children with severe–profound hearing losses were wearing their instruments at volume setting insufficient to overcome the auditory impairment. In fact, some of the children were receiving only minimal benefit from their hearing aids at the "as worn" volume setting.

It has been reported previously that persons select gain settings which appear insufficient to compensate for the hearing impairment (Gaeth and Lounsbury, 1966; Brooks, 1973; Martin, 1973; Skalka and Moore, 1973; and Bryne and Fifield, 1974). Brooks (1973) indicated that for every 2 dB of hearing loss, the average

hearing aid user employs a gain of 1 dB. In this investigation many children wore the volume control at gain settings which were less than one-half the amount of hearing impairment. For example, in a sample of 20 children with profound hearing losses ($\geq$90 dB) 45 percent used gain settings of 35 dB or less.

Three possible explanations for this result are proffered. First, the high distortion levels found in the "standard" condition with the control at maximum may have caused many of the children to wear gain settings at a lower level. Another cause may be poor fitting earmolds. Children may have reduced the gain levels in an effort to avoid excessive acoustic feedback. Finally, audiologists and other educational staff may not be training children to wear their hearing aids at appropriate gain levels. It is important that audiologists, teachers, and parents know the recommended gain setting for a specific child and to insure that the child is wearing this aid at the desired level. McCandless (1973) has offered an alternative explanation for low-gain settings. He purports that gain levels are reduced to avoid environmental sounds from exceeding discomfort levels. According to McCandless, discomfort levels seldom surpass 110 dB SPL for subjects with hearing losses up to 65 dB. A 40 dB gain hearing aid, then, can result in amplifying sounds of 75 dB into a discomfort range. The problem of gain-setting requirements among young children needs further study.

From the sample of 35 hearing aids, many failed to agree with the manufacturers' published specifications. Such a result lends additional support to the prevalent view that many children's hearing aids in the public schools are inadequate and are consequently providing minimal benefit to the user.

Finally, while it is apparent that many hearing aids in this study were not satisfactory, it is important to stress that the overall findings appear more promising than the results of previous research. An examination of earlier work (Peck, 1969; Coleman, 1972; Gaeth and Lounsbury, 1966; Zink, 1969) suggests that an average of 40–50 percent of children's hearing aids are malfunctioning. The results in the present study were somewhat better than this. This improvement must be attributed at least in part to the monitoring program of the audiologic staff. Unfortunately, too few public school systems employ educational audiologists.

Conclusions

The major findings of the report include:

1. In 27 percent of the hearing aids, the physical condition of the instrument was rated faulty.
2. Only 15 percent of the hearing aids used weak batteries.
3. For a "standard" measure, 48 percent of the hearing aids produced THD of $\geq$20 percent. In the "as worn" setting, 10 percent of the hearing aids used produced THD $\geq$20 percent.
4. Over 40 percent of the children set their volume controls at levels which produced gain values of $\leq$ 35 dB.
5. A minimum of 25–30 percent of a sample of hearing aids failed to agree with the manufacturers' specifications. Eighty percent of these aids did not meet specifications for a basic frequency response.

Recommendations

In view of the findings described in this report, it appears that public school programs need to intensify their efforts to monitor, trouble-shoot, and maintain the hearing aids of aurally handicapped children. The number of inservice training programs for teachers, speech and language pathologists, and ancillary staff needs to be increased. Teachers must concern themselves with the particular hearing-aid needs of their children. Parents should also continue to be a primary target for these programs. For all inservice training, the value of the educational audiologist, working in conjunction with public school staff, cannot be overemphasized.

The feasibility of training paraprofessionals or aides to monitor hearing aids should be explored. These persons could assist professionals in the intensive daily monitoring of children's hearing aids.

All school programs for the hearing-impaired should have immediate access to hearing aid testing equipment capable of measuring distortion products and frequency response curves. Many of the problems uncovered in this study could be quickly remedied if testing equipment were available. Such a recommendation does not seem unrealistic now that rather simple, inexpensive portable equipment is available.

In large educational programs for the hearing-impaired such as the special education division of Los Angeles, serious consideration should be given to employing a hearing aid repair technician to assist in maintaining children's hearing aids. Additionally, each educational program should have a large supply of components for a variety of types of hearing aids. Programs should also maintain a diversified number of stock hearing aids for the hearing-impaired children.

Finally, there appears to be a need to research hearing aid gain requirements among hearing-impaired children. Information is needed about the relationship between gain and such parameters as degree of hearing loss, audiometric configuration, differences in electroacoustic responses, and discomfort thresholds. The pros and cons of using fixed gain settings should also be explored.

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III

Electroacoustic Assessment of Children's Hearing Aids: Repeatability of Measurement and Determination of Merit

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At least three purposes for making electroacoustic measurements of hearing aids have emerged since Romanow (1942) first offered suggestions for standardizing such tests. While these purposes are not necessarily separable, they place distinctive demands on measurement strategies.

The most obvious goal for hearing-aid measurement is the engineering goal. Here, the task is to determine whether design criteria have been met, to ascertain contributions to total system variability arising from components, and to insure an acceptable level of quality control in the manufacture of hearing aids. Measurement strategies fulfilling these objectives must be accurate, reliable, efficient, and cost-effective. Examples of attempts to further these goals include standards documents issued by the Hearing Aid Industry Conference (HAIC, 1961), and by various standards organizations (American National Standards Institute—ANSI S3.3, 1960; ANSI S3.8, 1967; International Electrotechnical Commission—IEC 118, 1959).

A second goal can be termed scientific. Such measurement strategies have as their objective the identification of electroacoustic phenomena, and the discovery of cause-effect relationships among electroacoustic and perceptual events. Generalizations are sought which promote development of accurate, data-efficient engineering and clinical procedures for dealing with hearing aids and people. Especially important are the logical cross-connection laws linking the statistically average hearing aid user to the real listening world through engineering and clinical data (Chial and Hayes, 1974). Examples of this approach are given by Harris, et al. (1961), Jerger and Thelin (1968), and Burkhard and Sachs (1975).

A third objective is clinical. The task here is that of matching people to machines. The very difficult job faced by those who pursue this goal is to determine whether a particular aid provides maximum—or even acceptable—benefit to a given hearing-aid user. Here, methods are sought which are not only accurate, reliable, and efficient, but also which can validly predict the future function of hearing aids and the people who use them in their everyday lives (Chial and Hayes, 1974; Carhart, 1975). Examples of the clinical approach are found in the reports of Schumaier and Rintlemann (1973), Pascoe (1975), and Coleman (1972).

One concern shared by those with engineering, scientific, and clinical interests in hearing aids is the matter of performance tolerances—the limits within which an aid must function to remain within stated specifications. This concern is reflected in recent activities of standards writing groups (Academy of Rehabilitative Audiology—ARA, 1974; U.S. Food and Drug Administration—FDA standard proposal draft 5, 1975; ANSI standard proposal S3.22 draft 51, 1976).

The development and evaluation of tolerance criteria is especially important with respect to hearing aids used by children. It is well established that as a group, hearing-impaired children have the greatest need and the least ability to secure consistently adequate amplification. Coleman (1975) summarized the results of several earlier studies (Gaeth and Lounsbury, 1966; Zink, 1972; Coleman, 1972; Porter, 1973) with the observation that fully half of the hearing aids worn by children can be expected to function poorly or not at all. This disturbing obser-

vation persists despite the use of "very liberal minimum requirements for hearing aid performance" by independent investigators whose work spanned nearly a decade.

One factor not adequately known is how consistently proposed tolerance criteria can be applied to electroacoustic data obtained on children's aids under different conditions. The purpose of this study was to contribute an answer to this question. An important aspect of the question relates to the availability, quality, and sufficiency of comparative information (e.g., manufacturers' specifications for hearing aids). Existing standards methods were used for this reason.

Method

General Approach

Two classes of information were gathered from each hearing aid tested in this study. Both classes of data were obtained with the hope that judgments could be made about the general adequacy of a hearing aid, and (to some extent) about the adequacy of the device as operated by its user.

Qualitative data were acquired through a physical inspection of each aid and its battery. This information is similar to that sought in service inspections provided by hearing-aid suppliers, audiologists, and classroom teachers.

Quantitative data were gathered through standardized and specialized electroacoustic measurement procedures. This class of information is typical of what might be obtained at a manufacturing plant, service center, or audiology clinic. Data were gathered through field (Bess, 1976) and laboratory (present study) measurements of the same group of aids. Laboratory measurements were taken in a manner similar to that described by Bess except that different equipment was used, a different individual operated the equipment, and the data were gathered at different times.

Comparisons between field and laboratory electroacoustic data were sought to ascertain the reliability of such measurements, and to determine the consistency with which decisions can be made about hearing-aid adequacy. Additional comparisons related manufacturers' specifications to empirical information collected in the field and in the laboratory.

Hearing Aids: Selection and Description of Sample

Bess (1976) described selection methods, measurement procedures, and the results of a field study of 121 hearing aids used by children enrolled in the Special Education Division of the Los Angeles Unified School District. A sample of 16 aids was selected by Bess from this larger group tested in the field. Rental devices were provided to children whose aids were subjected to laboratory testing.

Hearing aids were to be surrendered in an "as worn" (AW) condition. Earmolds and batteries were removed, and gain and tone controls were secured in AW positions with adhesive tape. The aids were then shipped (with batteries, but without earmolds or tubing) to the Department of Speech Communication at the University of Texas at Austin for measurement. Approximately 3 days were spent in transit; the aids were inspected immediately following arrival.

Ten of the hearing aids were of the body type, while six were ear level devices. In all, eight manufacturers were represented. The aids differed widely in vintage and design: all were equipped with external gain controls and telecoil circuitry; 13 had either internal or external tone controls; five permitted adjustment of maximum power output; two were equipped with automatic gain control circuitry; and one had a directional microphone. Thus, the sample can be considered representative of the population of hearing aids used by hearing-impaired children. It was assumed that the sample also was representative of the group of aids tested by Bess (1976).

Qualitative Assessment

Objective

The purpose of this assessment was to establish whether judgments of hearing-aid adequacy could be made from direct observations which require little or no special facilities. All hearing aids were examined within 2 days of their arrival.

Procedure

Identifying information was cataloged indicating type of hearing aid, manufacturer, model, serial number, type of battery and receiver (if any), and project identification number. Gain, output, and tone-control settings (internal and external) were noted; considerable care was taken to mark or otherwise identify the AW positions of adjustable external controls.

One feature of the physical examination was battery voltage. Batteries were measured with a digital voltmeter (Tektronix DM 501) under each of three conditions. First, voltage was measured with no load applied to the battery. Although such measurements are common, they convey little information about the ability of a battery to supply current to a circuit. Therefore, the battery was placed in parallel with a 680 ohm load resistor for a period of 1 minute, whereupon a second voltage reading was taken. This load was selected to simulate a 1–2 ma current drain; a relatively short load duration was specified to minimize the effects of measurement on later electroacoustic assessment. The load resistor was removed, the battery allowed to recover for 1 minute, and a third voltage reading was taken. The difference between pre-load and post-recovery voltage was taken as a figure of merit for the battery under test: the smaller the measured difference, the better. A battery was considered defective if the first voltage measurement was more than 10 percent below the nominal value of the cell, or if the voltage difference between the first and third measurements exceeded 5 percent of the nominal value of the cell.

Hearing aids were inspected for evidence of corrosion, dirt, cracks in aid, elbow, or receiver, clogged sound paths, frayed cords, damaged connectors, etc. Each aid was fitted with a fresh battery and an earmold. External controls were checked for gross integrity. Variable gain and tone controls were checked for smoothness of operation (mechanical and acoustical), and freedom from noise. The input-selector switch and telecoil circuit were checked by placing the aid near a broad band electromagnetic noise source. Receiver cords and connectors were manipu-

lated gently to check for intermittency. Overall sound quality was checked by listening to music passages at each of several hearing-aid gain settings.

Data Reduction

Observations were recorded on a form devised for that purpose. Departures from ideal function were dichotomized as being "minor" (i.e., not likely to impair hearing aid performance) or "major" (i.e., of a type or magnitude likely to degrade performance).

Quantitative Assessment

Objective

These measurements were intended to describe the electroacoustic performance of the hearing aids pursuant to determinations of merit. Data were collected in two groups over a period of about 10 days following receipt of the aids.

Apparatus

Description. Like that reported by Bess (1976), the laboratory measurement method was an automatic comparison method. Figure 1 illustrates the equipment used to gather electroacoustic data in the laboratory. Swept-frequency, sine wave signals produced by a wave analyzer (General Radio 1523–P4) were routed to a level regulator (General Radio 1569), and then to a passive high-pass filter ($F_c = 50$ Hz). The filter output was directed to a power amplifier (MacIntosh 50), through a fuse to a loudspeaker (Radio Shack P/N 40–1341) housed in a test chamber (Bruel & Kjaer 4212). The inner walls of the test chamber (which simulates an anechoic space for the frequencies of interest here) were filled with sand.

A 1-inch pressure microphone (Bruel & Kjaer 4144) was fixed in a position within the test chamber. The output from this microphone drove an amplifier (Bruel & Kjaer 2608), then the control signal line of the level regulator. The function of the control channel was to sense the sound pressure level (SPL) generated in the test chamber, and to vary the output of the regulating amplifier such that the SPL seen in the test chamber was constant across a range of frequencies. Thus, the control channel compensated for irregularities in the frequency response of the loudspeaker, and for frequency nonlinearities arising from the interaction between loudspeaker and test chamber.

A second microphone-amplifier combination (identical to the first) was employed to sense the SPL generated at the output of a hearing aid. The measurement channel microphone was fitted with a 2 cm^3 acoustic coupler (Bruel & Kjaer DB 0138) that could be modified to accept either "button" receivers used with body aids, or tubing for connection to post-auricular devices. According to the manufacturer, this coupler meets the requirements of IEC standard R 126, 1961, ANSI document Z 24.9, 1949, and (essentially) ANSI 3.3, 1960. The Bruel & Kjaer 4212 test chamber has high-pass filters ($F_c = 150$ Hz), one in the output line of each microphone channel. These filters were engaged throughout this study.

A reversing switch permitted routing the signal from either microphone to the wave analyzer. The control channel signal was selected for level calibration, the

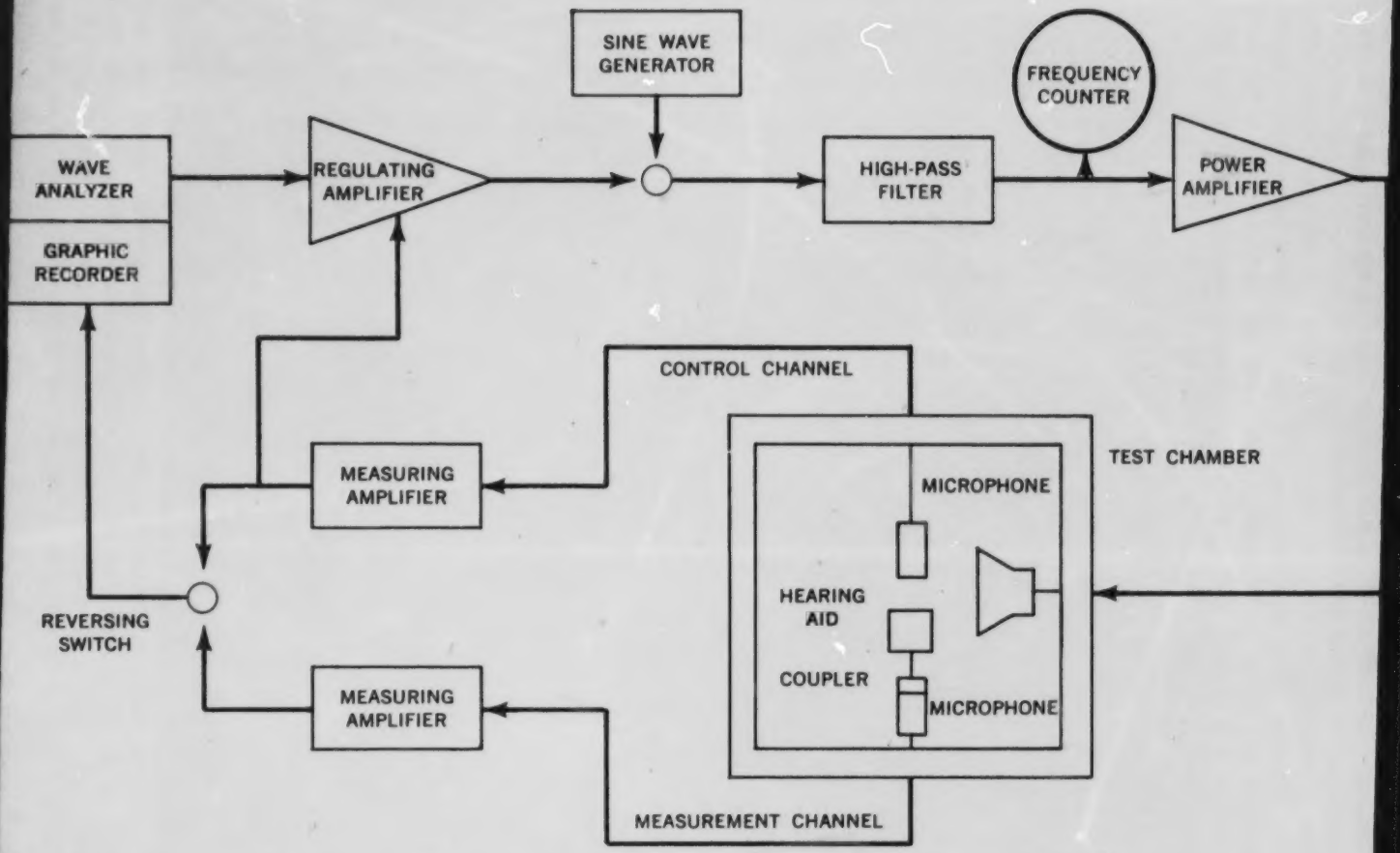

Figure 1.—Block diagram of instrumentation used to make electroacoustic measurements of hearing aids.

measurement channel signal for hearing-aid measurements. The wave analyzer was equipped with a tracking filter (100 Hz wide band-pass in this case) synchronized in frequency with the wave analyzer oscillator. The graphic level recorder (General Radio 1523 with 1523–9661 chart paper) produced a permanent amplitude vs. frequency record. The level recorder was equipped with a 100 dB range potentiometer.

An alternate signal generator (General Radio 1309–A) was used as a low-distortion source of fixed-frequency pure tones for measurements of harmonic distortion. A frequency counter (Ballantine 5500A) permitted calibration of frequency, and a microphone calibrator (Bruel & Kjaer 4230) was used to calibrate level.

Calibration. The instrumentation described above met or exceeded the relevant hearing-aid measurement system requirements for automatic comparison systems as described in IEC 118, 1959; ANSI S3.3, 1960; HAIC, 1961; ARA, 1974; FDA proposal draft 5, 1975; and ANSI S3.22 proposal draft 51, 1976. Compliance with tolerances given in these standards was verified by measurement before and after data were taken from hearing aids. The single exception to compliance may have been that relating to the effects of stray electromagnetic fields (field intensity was not measured); otherwise, the system was within stated tolerances with respect to frequency linearity, frequency accuracy, amplitude linearity, amplitude accuracy, recorder system accuracy, harmonic distortion, total system noise, and positional effects at the test point in the simulated anechoic space.

Running calibrations were made each time the test system was activated. One of these was a level-accuracy calibration. The sound-level calibrator was placed on each of the two microphones in turn. This device produced a 1.0k Hz tone at a SPL of 94 dB (re: 20μPa). With the calibrator on the control microphone, the control channel amplifier was adjusted to indicate 94 dB SPL at the amplifier. The graphic level recorder pen position control was set to yield an appropriate deflection for this signal. The calibrator was then placed on the other microphone and the sensitivity of the measurement channel amplifier was adjusted to produce an identical pen deflection. Thereafter, changes in input signal level were accomplished at 1.0k Hz with the regulating amplifier level control and verified with the control channel measurement amplifier. Frequency accuracy was calibrated with the digital frequency counter, which was always in parallel with the input to the passive filter immediately preceding the power amplifier.

All measurements were taken with the wave analyzer tracking filter engaged. Frequency response measurements were taken from 100 Hz to 6.5k Hz at a sweep speed of 10 seconds per decade frequency. Distortion measurements were taken from a lower frequency limit defined by the driving frequency (500, 700, or 900 Hz) to an upper limit of 6.5k Hz at a sweep speaed of 50 seconds per decade frequency.

Procedures

Hearing aids were measured under each of two analysis conditions. In the first condition (AW), gain, tone, and other controls were set as they had been when the aid was received. Presumably, these settings represented normal use conditions for the aids tested. The intent of AW measurements was to duplicate those taken under similar conditions in the field study. In the second condition (STD), hearing aids were operated in accord with ANSI S3.3, 1960 and in accord with

the measurement conditions indicated on manufacturers' specification sheets. The intent of STD measurements was to duplicate those made by hearing-aid manufacturers.

AW Condition

The battery shipped with the aid was inserted and controls were positioned as they had been when the aid was first examined. The aid was placed in the test chamber so that the microphone of the aid fell within a test area of approximately 3 cm^2 marked on the support screen. Thus, the hearing-aid microphone opening was perpendicular to the loudspeaker diaphragm and parallel to the plane of the control microphone. The 2 cm^3 acoustic coupler was attached to the measurement microphone. For body aids, the hearing-aid receiver was secured to the coupler by means of a standard rubber gasket, and the microphone-coupler assembly was placed in its receptacle outside the test cavity. The internal receivers of post-auricular aids were joined to the coupler by means of a ¾-inch length of number 15 AWG (id) flexible tubing and a nipple plate inserted in the coupler. For these aids, the measurement microphone-coupler assembly was placed inside the test cavity. The tubing used for AW condition tests had the same nominal dimensions as that used by Bess (1976).

The test chamber was sealed, a signal was introduced at a SPL of 70 dB, and a frequency response curve was recorded. This curve was considered the "basic response curve" for the AW condition. Additional frequency response curves were taken at input SPLs of 50, 60, 80, and 90 dB.

The wave analyzer oscillator and the level regulator were then disabled, and the low-distortion sine-wave generator was placed in circuit. This oscillator was successively adjusted to produce driving signals of 500, 700, and 900 Hz at a SPL of 70 dB. The wave analyzer was swept across the frequency range noted previously, for each of the three driving signals. The resulting curves characterized the nonlinear (harmonic) distortion of the aids.

STD Condition

Following AW condition tests, "standardized" measurements were made. Manufacturers' specification sheets were consulted for information about tubing dimensions, tone-control settings, power-control settings, and any other factors relevant to electroacoustic analysis. These conditions were duplicated for each aid. A fresh battery was inserted, and the aid was placed in the test chamber.

A 1.0k Hz signal was produced at a SPL of 60 dB. The gain control of the aid was adjusted to produce 40 dB (coupler) gain or full-on gain, whichever was less. A frequency response curve was then recorded. This was the "basic response curve" for the STD condition. Additional curves were recorded for input SPLs of 50, 70, 80, and 90 dB.

The alternate signal source was engaged, and pure tones of 500, 700, and 900 Hz were generated at a SPL of 75 dB. Harmonic distortion curves were taken for each of the three input signals.

The test chamber was opened, and the hearing-aid gain control was advanced to its full-on position. Frequency response curves were generated for input SPLs of 50, 60, 70, 80, and 90 dB. The output record produced by the 50 dB input

signal was considered the basic descriptor of acoustic gain under the STD condition. The result of the 90 dB input signal represented the performance of the aid at saturation. Typically (but not inevitably), a 90 dB input signal produces the greatest amplitude output signal an aid can provide. The saturation condition was verified for each aid by increasing the SPL of a 1.0k Hz tone to 100 dB. Finally, a full-on gain distortion series was run for driving frequencies of 500, 700, and 900 Hz at 75 dB SPL.

Other Information

The original curves generated by Bess (1976) in the field study under conditions analogous to the present AW and STD conditions were obtained. Thus, field and laboratory data were available for the same set of aids.

A set of derived indices of hearing aid performance were generated from raw data (curves). With the exceptions noted below, data reduction followed the procedures outlined in ANSI S3.3, 1960; HAIC, 1961; ANSI S3.8, 1967; and IEC, 118, 1959. Except for harmonic distortion, identical data reduction methods were followed for field and laboratory data sets.

Average acoustic gain was defined as the mean of the differences between input SPL and output (coupler) SPL at 500, 1.0k, and 2.0k Hz. Average acoustic gain is expressed in decibels re: input SPL. *Peak acoustic gain* was defined as the frequency (Hz) and coupler level (dB re: input SPL) at which the greatest gain was produced. These measurements were taken from (1) the STD condition gain curves produced at full-on gain and an input SPL of 50 dB, and from (2) the AW condition curves generated for an input SPL of 70 dB.

Average maximum power output (MPO), or average saturation output, was defined as the mean coupler SPL at 500, 1.0k, and 2.0k Hz with the aid set to full-on gain and with an input signal of 90 dB SPL. *Peak power output*, or peak saturation output, was defined as the frequency (Hz) and coupler SPL (dB) at which the greatest output amplitude was observed. These indices were computed from STD condition curves generated at full-on gain and an input of 90 dB SPL.

Bandwidth was specified as in ANSI S3.8, 1967. Average acoustic gain was computed for the "basic response curves" (AW condition—70 dB input; STD condition—60 dB input SPL with 40 dB gain at 1.0k Hz). A point 15 dB below average acoustic gain was located on the 1.0k Hz ordinate. A reference line was drawn from this point, parallel to the frequency axis. The points at which the reference line intersected the basic response curve designated a *low frequency cut-off* (F_L) and a *high frequency cut-off* (F_H).

Index of response irregularity (IRI) is a measure of the smoothness of a frequency response curve. Originally devised by Jerger and Thelin (1968) and modified for use here, IRI is not a part of existing hearing-aid measurement standards. However, it does permit numerical expression of the shape of a transfer function. A clear plastic template was built consisting of a base level line and a set of parallel lines separated by 2 dB intervals (relative to recorder paper dimensions) rising above the base level. A pair of ordinates marked the frequency limits of interest. The base line was aligned over the lowest excursion of the curve, and a count was made of how many times the transfer function crossed 2 dB intervals from 200 to 5.0k Hz. Different templates were used for field and laboratory data because chart paper scales were not the same. Ideal IRI can be defined as 0—

a perfectly flat frequency response. IRI was determined for "basic response curves" gathered in AW (70 dB input) and STD (40 dB gain for a 60 dB input SPL) conditions.

Total harmonic distortion (THD) was measured differently for field and laboratory data. This was necessitated by instrumental differences. For laboratory data, THD was defined as

$$\% \text{ THD} = 100 \frac{\sqrt{\sum_{i=2}^{N} A_i^2}}{A_1}$$

where A is sound pressure amplitude (in Pascals) and where the subscript denotes harmonic number. Operationally, THD was determined from wave analyzer curves by (1) finding the decibel difference between the output amplitude at the driving frequency and at each of several harmonics of that frequency; (2) converting each decibel difference to a ratio (percentage); and (3) finding the square root of the sum of the squared ratios. Computationally,

$$\% \text{ THD} = \sqrt{\sum_{i=2}^{N} P_i^2}$$

where P_i is the ratio (percentage) of energy at harmonic i relative to the fundamental (i = 1). THD values were determined for driving frequencies of 500, 700, and 900 Hz, then averaged and expressed as a percentage.

The approach outlined above differs from that given in virtually all extant and proposed standards for hearing-aid measurement. The defining equation cited in the standards is equivalent to:

$$\% \text{ THD} = 100 \sqrt{\frac{\sum_{i=2}^{N} A_i^2}{\sum_{i=1}^{N} A_i^2}}$$

Note that the denominator in the last equation includes the fundamental and all harmonics of the fundamental, whereas the approach taken in this study was to define the denominator in terms of the fundamental alone. In an ideal case the two approaches will yield the same result for measured THD up to about 10 percent; for larger amounts of distortion, the equation cited in the standards systematically underestimates distortion. Usually, devices that follow the approach given in the standards estimate the denominator simply by measuring the RMS amplitude of the entire output signal, including noise not harmonically related to the input signal. Thus, for low amounts of distortion and low amplitude driving signals (or noisy test locations), distortion may be overestimated. For these reasons, the index defined in the standards is more properly termed total harmonic distortion "factor." The index used in this study is "true" harmonic distortion (Tremaine, 1969, p. 1291). The distinction between the two definitions of THD

would be moot were it not for the fact that high distortion figures are common in hearing aids operated at or near saturation (Curran, 1976). It is probably incorrect to speak of hearing aid distortion as a unitary phenomenon—there will be as many types of distortion as there are ways to measure it (Burnett, 1976).

Field study THD curves were generated with a signal swept across the entire frequency range, rather than at a number of fixed frequency driving signals. Evidently field study equipment used the definition given in the standards and noted above (i.e., a tuned rejection filter). For these data, percent THD was read directly from distortion curves at frequencies of 500, 700, and 900 Hz. Resulting values were averaged and expressed as a percentage. For both data sets, percent THD was determined for the AW condition (70 dB input) and for the STD condition (at the 40 dB gain setting, and at full-on gain, both for a 75 dB input signal). STD condition measurements of THD correspond to ANSI S3.3, 1960.

Results and Discussion

Qualitative Assessment

Two of the 16 aids (12.5 percent) presented serious battery problems as worn: one aid was shipped with an almost fully discharged battery; another had no battery at all; a third aid had a battery that evidenced some corrosion. Thus, a total of 18.8 percent of the sample had minor or major battery problems. This failure rate is less than what has been found in previous studies (e.g., Coleman, 1972), but corresponds with the results of Bess (1976): 15 percent of the aids had batteries at less than full strength.

One aid (6.3 percent) had a damaged case and microphone sound path. Three others (18.8 percent) showed damage to receiver cord, case, or connectors. Three additional aids (18.8 percent) demonstrated minor receiver problems (e.g., hairline cracks in case). Two aids had controls with serious malfunctions, and three presented subjectively poor sound quality. In all, seven of the 16 aids (43.8 percent) evidenced one or more problems considered sufficient to adversely influence performance; 87.5 percent (14 aids) showed minor or major problems; and 12.5 percent appeared completely free from problems at the time of the qualitative assessment.

The basic failure rate of 43.8 percent may underestimate the actual status of this group of hearing aids for either of two reasons: First, since earmolds and connecting tubing were not available for inspection, some potential difficulties (e.g., feedback) could not be determined. Second, owners of the aids were reportedly involved in a hearing-aid maintenance program and may have been aware that their aids were to be evaluated. The present data indicate a failure rate somewhat higher than the 27 percent found by Bess (1976) in the field study of 121 aids. The difference in failure rates between the field study and the present effort is probably due to sampling effects and differences in the criteria of the respective examiners. Failure rates ranging from one-fourth to one-half seem consistent with other reports of similar assessments.

Quantitative Assessment

One difficulty faced in the analysis of these data was a reduction in sample size arising from incomplete manufacturer data (no information on one aid), field data (no information on one aid), and laboratory "as worn" condition data (two aids were untestable: one had no battery; the other was received with the gain control turned off). An aid was included in the analysis of a specific electroacoustic index only if complete data were available. This produced sample sizes ranging from 11 to 16 aids, depending on which electroacoustic measure was involved.

STD Condition Measurements

These findings relate to questions about consistency of measurement and the merit of hearing aids, *per se*, as opposed to the adequacy with which the aids were used by their owners.

Field, laboratory, and manufacturer data were summarized and statistical comparisons were made among the three data sets. The significance of mean differences among data sets was determined through analyses of variance (ANOVAs) and *post-hoc* t-tests, when indicated. The level of confidence for all statistical tests was $P_\alpha < .05$. Exact probabilities of observed F-ratios were found, as were estimates

Table 1.—Summary of results of selected amplitude measurements of hearing aids taken under standard conditions (ANSI S3.3, 1960). Empirical data were taken in field and laboratory settings.

		Average acoustic gain (dB)	Peak acoustic gain (dB)	Average maximum power output (dB–SPL)	Peak maximum power output (dB–SPL)
Laboratory assessment	$\bar{X}$	55.1	63.6	127.3	132.7
	S.D.	16.8	14.9	8.1	7.9
Field assessment	$\bar{X}$	52.9	63.9	128.8	133.6
	S.D.	17.3	15.1	11.1	11.8
Manufacturer data	$\bar{X}$	60.1	68.5	129.0	133.7
	S.D.	12.7	10.0	5.4	4.6
N		14	14	14	11
F		5.771*	1.993	.979	.158
P (F_{obs})		.009	.155	.624	.999
Strength of association	ω^2	.18	—	—	—

*F significant at $P_\alpha = .05$.

of the strength of the experimental effect (ω^2). ω^2 describes the proportion of score variation "accounted for" by the differences among data sets. Where pairs of data sets were compared, Pearson product-moment correlation coefficient (r) and coefficients of determination (r^2) were computed. r designates the similarity among data sets, while r^2 describes the proportion of score variance "accounted for" by the relationship between two sets of scores.

Table 1 presents the results of STD condition measurements of gain and saturation. Three of these indices produce very similar results for all three data sets: peak acoustic gain, average MPO, and peak MPO did not differ importantly across field, laboratory, and manufacturer measurements. However, field and laboratory estimates of average acoustic gain were both significantly lower than manufacturers' specifications (the two empirical estimates did not differ).

Table 2 (right half) summarizes STD condition measurements of F_L and F_H. Mean values for F_L did not differ significantly among the three data sets. However, field and laboratory measures of F_H were different. This occurred despite the fact that neither empirical data set differed significantly from manufacturers' specifications. An inspection of raw scores for F_H indicated that field results were consist-

Table 2.—Summary of results of selected bandwidth measurements of hearing aids taken under standard (STD) conditions (ANSI S3.3, 1960) and as worn (AW) conditions. Empirical data were taken in field and laboratory settings.

		As worn condition basic response curve (70 db input)		Standard condition basic response curve (60 dB input)	
		Low frequency (Hz)	High frequency (Hz)	Low frequency (Hz)	High frequency (Hz)
Laboratory assessment	$\bar{X}$	281.8	3895.5	292.1	3864.3
	S.D.	117.3	665.0	120.6	619.8
Field assessment	$\bar{X}$	336.4	4627.3	321.8	4578.6
	S.D.	120.1	1051.8	117.8	1026.7
Manufacturer data	$\bar{X}$	320.0	4109.1	344.3	4128.6
	S.D.	217.2	401.1	244.0	410.3
N		11	11	14	14
F		.597	6.421*	.584	6.593*
P (F_{obs})		.790	.007	.803	.005
Strength of association	ω^2	—	.24	—	.21

*F significant at $P\alpha = .05$.

ently higher than laboratory results. This may have been caused by acoustic coupler, microphone, or level recorder speed differences. In any event, it is almost certainly a measurement artifact.

Table 3 gives correlations indicating the similarity among the three data sets for the measures summarized in Tables 1 and 2. Field and laboratory measurements were markedly similar: the correspondence between the two sets of measurements accounts for 67–90 percent of the score variance. Correlations among (1) field and manufacturer data and (2) laboratory and manufacturer data suggest that the laboratory measurements were somewhat more consistent with prototypic specifications for these aids. That field and laboratory measures differed is not particularly surprising considering instrumental and other differences (Sinclair, 1976; Ely, 1976). The important implication is that at least some tolerance criteria will be influenced by the variations encountered between laboratory and field measurements.

The conclusions to be drawn from the results presented thus far are (1) as a group, the aids performed essentially as they were designed to perform and (2) field and laboratory measures were reasonably consistent. An exception to the first generalization is average acoustic gain: aids produced mean gain values 5–7 dB less than those indicated by the manufacturers. An exception to the second generalization relates to high-frequency cut-off: field data produced scores about 18 percent higher than laboratory data. However, neither empirical data set differed from specified data by more than about 11 percent.

Percent total harmonic distortion also was measured under STD conditions.

Table 3.—Pearson product-moment correlation coefficients (r) relating field, laboratory, and manufacturers' data gathered under standard conditions (ANSI S3.3, 1960).

	Laboratory data vs field data	Field data vs manufacturers' data	Laboratory data vs manufacturers' data
Average acoustic gain	0.95*	0.79*	0.88*
Peak acoustic gain	.94*	.53	.65*
Average MPO	.95*	.91*	.91*
Peak MPO	.91*	.86*	.80*
Low frequency cut-off	.94*	.39	.53
High frequency cut-off	.82*	.39	.33

*r significant at $P_\alpha = .05$; one-tailed.

These results are given in Table 4 for reference gain and full-on gain settings. Manufacturer data are not shown because they did not exist: in no instance was THD information given for the reference gain setting; in the two cases where such data were reported for the full-on gain setting, non-standard frequencies were used, precluding any comparison to empirical data.

As anticipated, both empirical data sets produced significantly higher THD scores for the full-on gain setting than for the reference gain condition. Field and laboratory measurements did not differ significantly for the full-on setting. Similarly, reference gain mean THD scores did not differ between field and laboratory data sets. These results suggest that the field and laboratory measurements were similar, but correlations between the two data sets indicate otherwise. Only the full-on gain setting produced a significant r (.75), accounting for 57 percent of the variance in THD scores. A reasonable interpretation is that there was no systematic relation between field and laboratory estimates of reference gain THD. Differences in the underlying definitions for harmonic distortion probably account for the poor correspondence between field and laboratory results for the reference gain condition, and for the apparent transverse interaction between the factors of data set and gain setting. As implied in the methods section (above), the instrumental solution to THD employed in the field study may have overestimated distortion in the reference gain condition and underestimated distortion in the full-on gain setting. Other possible sources of measurement error are differences in test chambers and loudspeakers (Curran, 1976).

Table 4.—Results of total harmonic distortion measurements of 12 hearing aids tested under three conditions of operation. Driving frequencies were 500, 700, and 900 Hz. See text for discussion of differences in measurement methods between field and laboratory data. Tabled values are percentages.

		As worn condition basic response curve (70 dB input)	Standard condition	
			reference gain (75 dB input)	Full-on-gain (75 dB input)
Laboratory	$\overline{X}$	4.1	5.8	21.1
	S.D.	3.6	6.7	13.8
Field	$\overline{X}$	7.1	8.4	19.3
	S.D.	6.8	8.7	15.4
Correlation coefficient	r	.32	.004	.75*
Coefficient of determination	r^2	.10	.002	.57
	t	1.60	0.87	0.60

*r significant at $P_\alpha = .05$; df = 10; one-tailed.

**t significant at $P_\alpha = .05$; df = 10; two-tailed.

Table 5.—Results of frequency response irregularity measurements of 12 hearing aids under two conditions of operation. Tabled values are counts.

		As worn condition basic response curve (70 dB input)	Standard condition basic response curve (60 dB input)
Laboratory			
	$\overline{X}$	12.1	12.3
	S.D.	6.6	7.8
Field			
	$\overline{X}$	21.8	22.3
	S.D.	9.4	9.1
Correlation coefficient	r	.30	.46
Coefficient of determination	r^2	.09	.21
	t	3.45*	3.99*

*t significant at $P_\alpha = .05$; df = 11; two-tailed.

Table 5 shows the results of field and laboratory determinations of frequency response irregularity made under STD conditions at the reference gain setting. The two data sets produced different results: laboratory measures indicated significantly less irregularity between F_L and F_H than did field measures. Moreover, the correlation between the two data sets was not significant. Higher IRI scores for field data probably are related to the fact that field estimates of F_H were higher than those made in the laboratory. Very obviously, these electroacoustic indices are not independent.

AW Condition

The results of as worn condition measurements are given in Table 6. Although field and laboratory mean estimates of average acoustic gain differed by about 7 dB, the differences were not consistent enough to be significant. Peak acoustic gain scores differ significantly between the two data sets, however. Neither index of gain—peak or average—resulted in a significant correlation between data sets. These findings complement those of Coleman (1972) and Kasten, Lotterman, and Revoile (1967) who observed considerable variability in gain curves as a function of time.

Mean THD scores were 4.1 percent and 7.1 percent for laboratory and field data, respectively. While these scores did not differ significantly, the two data sets were not highly correlated (r = .32; not significant). Both data sets produced THD scores lower than would be expected from prior research (Coleman, 1972; Lotterman and Kasten, 1967; Kasten and Lotterman, 1967).

AW condition measures of frequency response irregularity, F_L, and F_H presented a pattern of results very similar to what was found for STD condition measure-

Table 6.—Summary of results of selected electroacoustic measurements of 12 hearing aids as worn by their users and as measured under each of two assessment conditions. Measurements were made using an input sound pressure level of 70 dB (re: 20 μPa) as seen at the control microphone.

		Average acoustic gain (dB)	Peak acoustic gain (dB)	Total harmonic distortion (%)	Index of irregularity (Count) response	Low frequency (Hz)	High frequency (Hz)
Laboratory assessment	$\bar{X}$	28.1	36.3	4.1	12.1	314	3904
	S.D.	12.3	11.3	3.6	6.6	158	635
Field assessment	$\bar{X}$	35.7	46.7	7.1	21.8	352	4658
	S.D.	11.6	10.2	6.8	9.4	126	1009
Correlation coefficient	r	.38	.31	.32	.30	.84*	.95*
Coefficient of determination	r^2	.14	.09	.10	.09	.71	.91
	t	1.97	2.83**	1.60	3.45**	1.53	5.95**

*r significant at $P\alpha = .05$; df = 10; one-tailed.

**t significant at $P\alpha = .05$; df = 11; two-tailed.

ments: field data produced significantly higher values for IRI and F_H; F_L results were essentially the same.

Comparing AW condition measures to manufacturers' data provides some insight into the relationship between potential and typical hearing-aid performance. One index of interest is average acoustic gain. The AW gain setting produced significantly less gain for field data ($t = 8.11$; $df = 10$; two-tailed) and for laboratory data ($t = 8.34$; $df = 10$; two-tailed). for the laboratory data set, the relationship between AW condition and manufacturers' estimates of gain accounted for only 34 percent of the score variance ($r = .59$, significant). For the field data set, the correlation between AW condition and prototypic definitions of gain was ($r = .61$, significant), leaving 62 percent of the total score variance unaccounted for. The AW condition also produced appreciably less gain than was found in the empirical STD condition (see Table 7). Obviously, users of these aids received significantly less gain than the aids were capable of providing. While this may suggest problems for effectiveness of use, it also indicates that children operate aids at levels well below saturation (gain is specified as a full-on index by the standards). These results are consistent with those of Martin and Grover (1976), who reported that a large group of children with no signs of loudness recruitment tended to operate their aids at 4.2 dB of gain for each 10 dB of hearing loss (both measured at 1.0k Hz).

Table 7.—Results of average acoustic-gain measurements of 12 hearing aids under two conditions of operation. Tabled values are given in decibels (re: input sound pressure levels noted).

		As worn condition basic response curve (70 dB input)	Standard condition Full-on (50 dB input)
Laboratory	$\bar{X}$	28.1	54.4
	S.D.	12.3	16.7
Field	$\bar{X}$	35.7	51.5
	S.D.	11.6	17.4
Correlation coefficient	r	.38	.96*
Coefficient of determination	r^2	.14	.92
	t	1.97	2.10**

*r significant at $P_\alpha = .05$; df = 10; one-tailed.

**t significant at $P_\alpha = .05$; df = 11; two-tailed.

As shown in Table 4, the hearing aids were operated by their users in ways that produced somewhat less THD than what was found under either STD condition in which THD was measured. AW condition THD did not differ significantly from STD condition reference gain setting THD for either field or laboratory data set. However, for both data sets, AW condition THD was significantly less than what was found in the empirical STD test condition when aids were operated at full-on gain.

Estimates of F_L, F_H, and IRI made in the AW condition did not differ significantly from similar estimates made in the STD condition. This was the case for both field and laboratory data sets.

Determinations of Merit

One purpose of this study was to use available data and suggested tolerance criteria to answer questions about the merit of the hearing aids tested under laboratory and field conditions. Three proposed standards include electroacoustic performance tolerances (ARA, 1974; FDA proposal draft 5, 1975; ANSI S3.22 proposal draft 51, 1976). The standards offer criteria which differ in absolute value, and the three documents are dissimilar with respect to operational definitions for individual electroacoustic indices. Moreover, proposed tolerance criteria are based on measurement methods and data reduction procedures that depart significantly from those used here and advocated in ANSI S3.3, 1960, and ANSI S3.8, 1967. For these reasons, there is a legitimate question about the validity of applying such criteria to the present data.

It appears that the rationale for specific criteria given in at least two of the proposed standards (FDA proposal draft 5, 1975, and ANSI S3.22 proposal draft

51, 1976) is based upon manufacturing tolerances for the components of hearing aids; e.g., resistors (Olsen, 1976; de Boer, 1973). Some tolerance limits appear to be largely arbitrary. If these observations are correct, then differences among definitions of measures become less important than the need for close correspondence between empirical data and the specifications to which they are compared. For this reason, and because available manufacturers' data were (nominally) defined and gathered in terms of ANSI S3.3, HAIC, and ANSI S3.8 standards, it seems reasonable to apply the tolerance criteria given by the proposed standards to the present data.

Decisions about the adequacy of a hearing aid can be made using relative and absolute tolerance limits. An example of a relative criterion is one that states that average MPO for an aid should be within ±4 dB of prototypic specifications (ANSI S3.22 proposal draft 51, 1976). An absolute criterion is one requiring that average MPO should not exceed 135 dB SPL (ARA, 1974), or one stating that THD should not exceed 10 percent (ARA, 1974). Such criteria were applied to prototypic specifications and to the field and laboratory data gathered here under STD conditions. Not all of the tolerances stated in the proposed standards could be applied because some information was not available from manufacturer data sheets.

Results of allowable comparisons are given in Table 8. Significance tests were not performed on these results. One electroacoustic index for which data existed was average acoustic gain. ANSI S3.22 proposal draft 51 states that measured full-on gain shall be within ±5 dB of that cited by the manufacturer. Using this rule, nine out of 14 aids tested in the field (64 percent) and eight of 15 aids tested in the laboratory (53 percent) failed to meet specifications. Identical failure rates were found using the ±4 dB criterion given by FDA proposal draft 5 (the third standard—ARA, 1974—specifies no tolerance limit for average acoustic gain). These failure rates seem appreciably higher than the 38 percent reported by Bess (1976) for a group of 35 aids.

Several tolerance limits have been proposed for MPO. ANSI S3.22 proposal draft 51 lists a relative criterion of ± 4 dB for average MPO, while FDA proposal draft 5 cites a criterion of ± 3 dB for peak MPO. Forty percent of the field-condition aids and 47 percent of the laboratory-condition aids failed to meet the ANSI criterion. Using the FDA tolerance limit, 45 percent of the aids measured in the field and 67 percent of the same aids measured in the laboratory failed to meet specifications. These values compare to a 30 percent failure rate for average MPO for the 35 aids analyzed in the field study. The ARA proposal places an absolute upper limit of 135 dB SPL on peak MPO. For the present aids, failure rates were found to be 40 percent and 31 percent for field and laboratory data sets, respectively.

The ANSI and FDA proposals state that the THD of a hearing aid shall be noted, but no tolerances are given. The ARA proposal states that an aid shall produce no more than 10 percent THD when operated at a level 10 dB below saturation. It was felt that the STD condition reference gain setting approximated this operating level, since all but two aids achieved the reference output level at less than full-on gain. For this condition, then, failure rates were 17 percent for the laboratory data set and 33 percent for the field data set. Applying the 10 percent rule to full-on gain setting measurements, 67 percent of the aids measured in the laboratory failed to meet criterion; 50 percent of the same aids tested in the field were not within specifications. These failure rates compare to a somewhat higher rate of 74 percent for

Table 8.—Failure rate percentages and proportions (in parentheses) for hearing aids measured under standard conditions and compared to manufacturers' specifications for selected electroacoustic indices.

		Field data	Laboratory data
Average acoustic gain	±5 dB (ANSI)	64% (9/14)	53% (8/15)
	±4 dB (FDA)	64% (9/14)	53% (8/15)
Maximum power output	±4 dB, average (ANSI)	40% (6/15)	47% (7/15)
	±3 dB, peak (FDA)	45% (5/11)	67% (8/12)
	<135 dB, peak (ARA)	40% (6/15)	31% (5/16)
Total harmonic distortion	<10% (ARA)	33% (4/12)	17% (2/12)
Low frequency cut-off	±20% (Present study)	71% (10/14)	47% (7/15)
High frequency cut-off	±20% (Present study)	50% (7/14)	27% (4/15)

the 35 aids measured by Bess (1976) at a full-on gain setting. The 10 percent maximum allowable THD criterion was also applied to distortion data gathered in the AW condition, though these results are not given in Table 8. For the field data set, 27 percent (4 out of 15) aids had THD in excess of 10 percent; for the laboratory data set, 15 percent (2 out of 13) aids failed to meet the 10 percent maximum THD criterion. Comparatively speaking, these results seem encouraging, but it must be recalled that many children operate aids at gain levels so low that the benefit from amplification is questionable. If the two aids that could not be tested in the laboratory AW condition were actually being used as they were received, these are indeed conservative estimates of failure rates.

All three proposed standards cite tolerances for frequency response curves measured under some definition of reference gain ("basic frequency response"). Origi-

nally, it had been planned to apply these tolerances to empirical curves. However, manufacturers' basic frequency response curves were available for only two of the 15 aids for which prototypic specifications were obtained. Of course, this is contrary to the measurement guidelines of the Hearing Aid Industry Conference (HAIC, 1961), as well as IEC—118, 1959; ANSI S3.3, 1960; and ANSI S3.8, 1967. Such failure to comply with standards is not at all uncommon. An alternative approach was developed wherein empirical and prototypic data were compared in terms of low frequency cut-off and high frequency cut-off. Consistent with the apparent rationale underlying the specification of tolerances in ANSI S3.22 proposal draft 51 and FDA proposal draft 5, a criterion of ± 20 percent was designated. For F_L, 71 percent of the aids in the field data set were considered out of specification, while 47 percent of the laboratory data set aids failed the criterion. For F_H, failure rates were 50 percent for the field data set and 27 percent for the laboratory data set. For the response curves gathered in the field, 93 percent of the aids (13 out of 14) failed to meet the ± 20 percent criterion for *either* F_L or F_H. Sixty-seven percent (10 out of 15) of the aids measured in the laboratory failed to meet *either* F_L or F_H specification. These last figures correspond to the 80 percent failure rate for frequency response curves found by Bess (1976) in the field study of 35 aids.

To summarize, each of the 15 aids (100 percent) assessed under STD conditions in the laboratory failed to meet one or more of the electroacoustic tolerances given in Table 8. Sixty-seven percent failed two or more tolerance criteria, and 33 percent failed three or more criteria. The field data set produced somewhat poorer results: all of the 14 aids (100 percent) failed one or more tolerance comparisons; 86 percent failed two or more; and 50 percent failed three or more criteria. Even though significance tests were not performed on computed failure rates, it is evident that field and laboratory data sets produced different estimates of merit for the same group of aids tested using comparable methods. This is not surprising when it is recalled that the two data sets produced significantly different estimates of F_H, THD, and IRI. It is further evident that the field study of 35 aids (Bess, 1976) produced different estimates of failure rates than did either of the data sets discussed here.

Failure rate results were compared for qualitative and quantitative assessment strategies. For this purpose, an aid was considered defective if it failed two or more of the quantitative tolerance criteria given in Table 8, or if one or more "major" failures were detected during qualitative inspection. Results are given in Table 9. For the laboratory data set, four of 15 aids (27 percent) were considered inadequate by both assessment methods. The percentage of similar merit determination outcomes for the two assessment methods can be summed to yield an estimate of net agreement between the methods. Similarly, percentages of dissimilar outcomes can be added to estimate net disagreement. Dividing agreement outcomes by disagreement outcomes yields an estimate of the overall correspondence between the two assessment methods. This ratio is 0.67, somewhat less than what would be expected due to chance alone (1.0). This approximation to detection analysis suggests that even a fairly rigorous quality assessment produces failure identifications substantially different from those found through electroacoustic measurement. It is noteworthy that the two aids that could not be tested electroacoustically in the laboratory AW condition (one had no battery; the other was turned off) were correctly identified as faulty through qualitative assessment, but not through STD condition quantitative measurement.

Table 9.—Comparison of failure rates for hearing aids assessed qualitatively and quantitatively. See text for details.

		Quantitative assessment (standard condition laboratory data set)	
		Pass	Fail
Qualitative assessment	Pass	13% (2/15)	40% (6/15)
	Fail	20% (3/15)	27% (4/15)

General Discussion

The findings described here are discouraging to say the least: 100 percent of the aids tested in the field or in the laboratory failed at least one tolerance criterion. However, several factors must be kept in mind in interpreting these results:

First, different measurement equipment, different equipment operators, and/or different test times can produce significantly different results. This can occur despite reasonable attempts to maintain consistent measurement strategies and considerable effort to insure that different instrumentation systems meet the requirements of existing standards. Similar results are reported by Sinclair (1976) and Ely (1976). This finding has implications not only for the reliability with which decisions of merit can be made but also for the validity of such determinations.

Second, comparisons between prototypic data and empirical data produce judgments about the merit of hearing aids, *per se*, and not necessarily about the benefit (or lack of benefit) a given aid may provide to a given hearing aid user. Obviously, extreme failures to meet tolerances (say, a THD of 60 percent) bode ill for successful hearing-aid use. But the importance of less extreme failures (say, a THD of 15 percent) has not been established. With respect to THD specifically, strong arguments can be made supporting the *desirability* of values in excess of 10 percent (depending on how distortion is produced and what other signal processing may accompany it—e. g., Thomas and Sparks, 1971; Smaldino, 1972; and Chial, 1973). The point is that "distortion" (however defined) is not necessarily bad. Some transmission system non-linearities improve performance for some listeners. The criteria given in standards proposals may or may not serve the needs of engineering quality control, but they are not universally accepted as being relevant to scientific or clinical electroacoustic measurement needs (Curran, 1975). It should be noted that virtually all the available engineering guidelines for hearing-aid design rest upon factors relevant to adults, not children (e. g., the articulation index). The needs of children, who are in the process of acquiring speech and language, may be very different from the needs of adults (Carhart, 1975). At best, proposed tolerances can contribute information about whether an aid is functioning as it was designed to function. The tolerances say nothing about the wisdom or value of the design, nor about the wisdom with which electroacoustic and audiometric data may have been used to match children to aids, nor about the benefit provided by a given aid.

Third, it has been obvious for some time that existing measurement standards

(most particularly, the current favored acoustic couplers) do not produce data very similar to what is observed in real ears (see Chial and Hayes, 1974, for review). Thus, there exists no necessary connection between moderate departures from tolerance limits and what would be expected to occur in the auditory canal of a hearing-aid user. Existing 2 cm^3 couplers are designed as limited simulations of the peripheral auditory systems of adults, not children. Indeed, differences between couplers and ears are probably more important than departures from specifications, up to and including the relative tolerance limits given in proposed standards. It cannot be assumed that two aids which meet tolerance criteria for a given design will produce the same benefit for a specific hearing-aid user.

Fourth, there is the matter of how extensively and specifically manufacturers' data are used in selecting amplification for a given child. If such data were critical to the selection of amplification and if the validity of this use of electroacoustic information were demonstrated, then the outcome of failure analyses like that presented here would be extremely important. The simple fact is that except for fairly general guidelines, we do not really understand what is required to provide optimum benefit from amplification (Martin and Grover, 1976). Carhart, in one of his last published statements on hearing aids, summarized this problem most succinctly when he stated that we are without benefit of a systematic theory of hearing-aid application (Carhart, 1975).

Finally, it must be stressed that the most direct (and probably the best) way to answer questions about the adequacy of a child's hearing aid is to measure listening performance with the aid adjusted as it is worn by the child. This approach entails its own very serious problems, for children—especially young children with limited or nonexistent oral-aural skills—are often quite difficult to test. Nevertheless, behavioral confirmation of the probable effects of misuse or underuse of amplification is necessary. Some work has been done along these lines (Brooks, 1973; Byrne and Fifield, 1974; Asp, 1975; Pascoe, 1975; Martin and Grover, 1976), but considerably more data are needed on a broader range of electroacoustic parameters, listening conditions, and age groups.

Conclusions and Recommendations

This project attempted to assess the consistency with which electroacoustic measurements can be made of childrens' hearing aids and the consistency with which such data can be used to answer questions about the integrity or merit of these aids. Also of interest was the consistency with which qualitative and quantitative assessments of hearing aids identify faulty devices. The same group of hearing aids used by children were measured under field and laboratory conditions. The two measurement conditions differed with respect to equipment, operators, and the time at which measurements were taken. Electroacoustic performance tolerance limits were selected from among those advocated by currently proposed standards for the electroacoustic measurement of hearing aids. Conclusions are as follows:

1. Hearing aids worn by children tend not to be within suggested tolerances of manufacturers' specifications. Two estimates of failure rate emerging from this study are 86 percent (field data) and 67 percent (laboratory data). All of the aids tested in the field (N = 14) or in the laboratory (N = 15) failed

at least one electroacoustic tolerance check.

2. Different instrumental methods yield different estimates of some electroacoustic indices. Those measures least affected were average acoustic gain, peak acoustic gain, average maximum power output, and peak maximum power output. Indices most affected were those related to details of transfer functions.
3. Differences in instrumentation produce differences in merit determinations. This was so for groups of aids, as well as for individual aids.
4. Qualitative and quantitative assessments of hearing aids yield dissimilar judgments of merit. This was the case for groups of hearing aids and for aids considered individually.
5. Some questions about hearing-aid adequacy cannot be answered because of insufficient comparative information from manufacturers: hearing-aid producers typically do not adhere to existing industry standards for electroacoustic measurement.
6. Some questions about the adequacy of a hearing aid as worn by a particular child cannot be answered because of inadequate information about auditory impairment.
7. Specific criteria for electroacoustic and other determinations of merit are important factors in judging hearing aids, *per se*, and in evaluating aids as worn by their users.

Efforts to insure consistent and adequate performance of hearing aids used by children need to be increased. This oft-made statement of need is in no way diminished by the problems of technical measurement discussed here. One—but only one—aspect of this effort should be electroacoustic monitoring of hearing aids. The problems associated with such measurement suggest the need to approach the design of monitoring programs with some caution. The use of electroacoustic tolerance limits and other criteria for verifying hearing-aid performance must be tempered by recognition of (1) the effects of differences in measurement equipment and methods, even when those differences seem to be minor, and (2) the distinctions between issues of engineering quality control and audiological-educational benefit. The availability of relatively inexpensive electroacoustic measurement equipment is by no means a panacea. Many serious faults can be detected only through careful physical inspection. Many such faults will be completely missed by standardized electroacoustic measurement regimens.

The best considered program for monitoring hearing aids through application of rational tolerance limits will be of little value unless more complete and better documented data are provided by hearing-aid manufacturers. Except for the most blatant problems, the absence of such information leaves us with a severe "rubber yardstick" problem. It cannot be stressed strongly enough that producers of hearing aids should conform to some identifiable standard for electroacoustic measurement. Some firms already have an excellent record in this respect. All firms need to accept a national standard and abide by it.

The important role of the child's hearing aid needs to be stressed to every person in a position to help that child. This includes teachers and parents, audiologists, hearing-aid dealers, and school administrators. Teachers are especially important, for it is the classroom teacher who is most often regarded as an authority by the child and by his parents. If the teacher is unconcerned, or is unsure about what a

hearing aid is and how it works, then the services of even the finest support team may be inadequate. A primary objective for the teacher should be to motivate the child to accept responsibility for his own hearing aid as soon as possible.

Serious consideration should be given to the development of physically more robust hearing aids equipped with "child-proof" controls that can be set in fixed positions.

Additional effort should be directed toward the refinement of hardware devices capable of monitoring hearing aids *in vita*. Preferably, these devices should be capable of simple retrofit to existing aids, and should produce an easily noticed signal in the event of failure. "HAMDU" (Hearing Aid Malfunction Detection Unit) is one such device which shows great potential (Roeser, Gerkin, and Glorig, 1976).

More information is needed relating electroacoustic events in aids as obtained with existing and proposed standards to what happens at the child's eardrum. In other words, we need validating information for electroacoustic measurements. This suggests the need for (1) acoustic couplers that more closely model childrens' external ears, (2) more exacting tolerances for electroacoustic measurement systems, and (3) serious consideration of other electroacoustic indices of performance (e.g., intermodulation and transient distortion). Results of these and other efforts may help us phrase electroacoustic tolerance limits with realistic implications for habilitation and rehabilitation.

Finally (and perhaps most importantly), there is a need to learn more about the effects of hearing aids on the child's auditory perception of his world. More information is needed relating the electroacoustic parameters of hearing aids *as worn* to children's auditory abilities and deficits. If information of this type can be gathered from both successful and unsuccessful users of amplification, we may be better able to devise rational guidelines for selecting and configuring hearing aids for children. What is called for here is a behavioral "failure analysis" similar to the electroacoustic failure analysis permitted by specification tolerances. Of course, this implies the need to discover or invent efficient and effective audiological methods for assessing listening behaviors in aurally handicapped children.

All of these efforts must recognize the inherent circularity of the problem of relating electroacoustic and psychoacoustic data. Neither class of information constitutes a clear and simple "truth reference" for the other. If hearing-aid technology is to continue to progress, it must do so through the closest possible cooperation of those engineering, scientific, and clinical interests in hearing impaired children.

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Guidelines for Audiology Programs in Educational Settings for Hearing-Impaired Children

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Preface

These "guidelines" are the fifth revision of a document drafted 4 years ago by the Joint Committee on Audiology and Education of the Deaf. They reflect a great deal of input from educators and audiologists with compromises among differing points of view. These "guidelines" have been approved by the Legislative Council and the Executive Board of the American Speech and Hearing Association (ASHA) and by the Executive Committee of the Conference of Executives of American Schools for the Deaf (CEASD). The Association and the Conference are the parent groups of the Joint Committee.

The document speaks for itself. In this preface we report some of our observations made on the path toward acceptance of the "guidelines" and our thoughts about their implementation.

In none of the doubts, reservations, suggested revisions, or requests for clarification that we received did anyone question the validity of the three premises upon which the document is based: (1) the normal primacy of the auditory channel for speech and language development, (2) the evidence relating to the extent of residual hearing among "deaf" children, and (3) the currently inadequate exploitation of residual hearing. This is a heartening observation, especially considering that we sought opinions from those on either side of the oral/manual controversy. The primary cause for concern about the guidelines was economic: where would the money come from to implement such recommendations as the audiologist/pupil ratio.

The members of the Joint Committee recognize the economic realities of our time. Many of us are, or have been, administrators of schools. We know the difficulty administrators have in securing adequate funding, even for worthwhile purposes. But this is precisely the task administrators face: acting primarily as educators and child advocates, to convince financial sources to support educationally sound programs, and then to allocate existing resources to reflect educational priorities. The availability of accepted guidelines for audiology services makes it possible for the audiology component of educational programs to compete with other components for limited financial resources.

We should like to see the "guidelines" implemented immediately in all educational settings serving hearing-impaired children throughout the country. We know that is not going to happen. We do believe that educators who are serious about the use of residual hearing for hearing-impaired children will do their best to begin the process toward implementation. As the process develops we expect to experience problems as well as positive support for the guidelines, to learn from these experiences and to modify future guidelines accordingly. We have simply made a beginning. The performance of hearing impaired children in the future will guide our future efforts.

Guidelines

Many preschool and school-age children have hearing impairments severe enough to affect their ability to function normally in an educational setting. Although each child has a legal, constitutional right to comprehensive quality services in educational settings, fewer than 50 percent are currently receiving appropriate services (Weintraub, Abeson, and Braddock, 1971). The position taken in these guidelines is that audiology programs should be an integral part of comprehensive services to hearing-impaired children in educational settings (ASHA, 1973).

These guidelines are not intended to cover identification audiometry programs. Although identification audiometry should be an integral part of a total audiological service for all children within any given school system, these guidelines are for programs in which children have already been identified as having a hearing impairment and requiring special educational and habilitative services. The American Speech and Hearing Association adopted Guidelines for Identification Audiometry in November 1974 (ASHA, 1975).

The term educational settings refers to organized programs of instruction, in private or public and residential or nonresidential environments, for hearing-impaired children who manifest special educational needs as a result of their hearing impairment. The rationale for organizing comprehensive and intensive audiology programs in these settings is based on three interlocking factors:

1. The auditory channel is the route through which speech and language development normally takes place. The human being's development of speech and language appears to be based on innate, biologically programmed factors (Lenneberg, 1967; Fry, 1966) which can be exploited most effectively through an auditory input (Liberman, et al., 1967). The use of other approaches for teaching initial language and speech skills to hearing-impaired children must be considered inadequate, though frequently necessary, substitutes for the "real thing."

2. Most hearing-impaired children possess significant residual hearing capacity (Goodman, 1949; Huitzing, 1959; Eliott, 1967; Boothroyd, 1972; Hirsh, 1973). Interpreted pessimistically, these studies show that from one-half to two-thirds of the children enrolled in schools for the deaf have potentially useful residual hearing. This is precisely the population of hearing-impaired children expected to manifest the most severe hearing losses.

3. Efforts to employ maximally the residual hearing of most hearing-impaired children generally have met with little success. The evidence clearly demonstrates that at any one time, at least half the children's hearing aids can be malfunctioning; that many of the children who possess hearing aids do not routinely wear them; and that children who can potentially benefit from amplified sound do not even own a hearing aid (Gaeth, Lounsberry, 1966; Zink, 1972; Findley, Winchester, 1972; Coleman, 1972; Northern, et al., 1972; Skalka, Moore, 1973; Porter, 1973). Classroom auditory trainers frequently fare little better than personal hearing aids (Matkin, Olsen, 1970a; Matkin, Olsen, 1970b; Wilson, Hoversten, Thies, 1972; Sung, Sung, Angelelli, 1973; Matkin, Olsen, 1973), and the poor acoustic conditions existing in classroom

environments limit the effectiveness of even appropriate amplification (Ross, 1972). Finally, the great care needed to ensure individualized electroacoustic packaging to the impaired ear is seldom realized (Ling, 1964; Genge, 1971; Gengel, Pascoe, Shore, 1971; Sung, Sung, Angelelli, 1971; Danaher, Osberger, Pickett, 1973; Erber, 1973). These problems are understandable in view of the understaffed and ill-equipped audiology programs typically found in educational settings, and they are not likely to be remedied without a dedicated effort to strengthen these programs.

These guidelines attempt to describe the audiological conditions necessary for the exploitation of the auditory channel for speech and language development to the degree permitted by the residual hearing capacity of a hearing-impaired child. Schools and society are investing large sums of money in hearing aids, auditory trainers, and other audiological equipment. This investment is a wasteful expenditure unless this equipment is properly used and performing according to specifications. It is unrealistic to expect overburdened administrators and teachers to supervise the full exploitation of residual hearing in addition to their many other responsibilities. In regular and special education programs, the assistance of such resource personnel as psychologists, media specialists, guidance counselors, remedial-reading specialists, and learning disability teachers is welcomed. All of these specialists are finding a fruitful field for their endeavors. In educational programs for the hearing impaired, however, the audiologist, a resource person with skills to ensure the maximal exploitation of residual hearing is either absent, in short supply, or inadequately supported. The inclusion of well-educated audiologists is necessary to implement the commitment of educators to use optimally the residual hearing most hearing-impaired children possess.

Not all educational settings may be in a financial position to implement the entire program immediately. Possibly some of the suggested functions of audiologists will seem uselessly esoteric while others may need to be added or modified. Nevertheless, unless there is agreement on an eventual goal and informed commitment to high standards, improvement in audiological services is not likely to occur. It is expected that each step in the implementation of these guidelines will justify and support further steps until the entire program can be implemented. Certainly, modifications in the guidelines should be made as experience with their use accumulates. Some educational settings may find it financially desirable and convenient to contract for some or all audiology services with already existing facilities in their communities. In these instances, it is important that the spirit of these guidelines be adhered to, in that such arrangements should result in comprehensive and coordinated services to the child, parents, and educational staff. In any event, community-wide and inter-agency planning is desirable to minimize unnecessary duplication of professional services. It is emphasized that vastly improved audiological services will not be a panacea for speech and language problems. Miraculous cures are not likely to result, but improved performance in a significant number of children should occur. Intensive audiological intervention is deemed appropriate regardless of the "educational method" being used. There is no intent in these guidelines to favor, explicitly, or implicitly, any particular education approach.

Personnel

1. One audiologist with a Certificate of Clinical Competence (CCC) in Audiology or its equivalent for approximately every 75 hearing-impaired children receiving special instructional and habilitative services in the educational setting.
2. A Director of Audiology (with either M.A. or Ph.D.) with a CCC in Audiology or its equivalent in any program where there are three or more audiologists. The Ph.D. degree is advisable in settings committed to a program of research.
3. One electronics technician for every 100 to 150 hearing-impaired children.
4. One full-time secretary/clerk for programs with three or more individuals on the staff. Part-time assistance will be needed in programs with one staff audiologist.
5. One or more audiometric assistants.
6. One or more consulting otolaryngologists.

Equipment

1. One sound-treated double room for programs with one audiologist and two sound-treated double rooms for every three audiologists employed. The dimensions of the test rooms should be sufficiently large to permit pediatric and hearing-aid evaluations in the sound field.
2. One two-channel clinical audiometer will be needed for each sound-treated double room, including the associated sound-field speakers and amplifiers.
3. A stock of loaner hearing aids in good working condition, along with extra cords, batteries, and receivers. It is assumed that all children will have their own hearing aids and that classroom auditory training units will be available.
4. Equipment for analyzing the electroacoustic characteristics of hearing aids and auditory training systems.
5. Instrumentation for impedance audiometry.
6. A sound-level meter and appropriate equipment for calibration of pure-tone and speech audiometers.
7. Ear-impression material kit, instamold kit, stock earmolds, hand grinder, earmold cleaners, and other miscellaneous earmold equipment.

Job Descriptions

Audiologist

1. Conduct comprehensive and periodic audiological assessments for each child. Younger children should be assessed as often as necessary to establish consistent, valid measures. Other children should be tested annually or whenever questions arise. Newly enrolled hearing-impaired students should be given a complete audiologic assessment. Additional audiological assessments may be needed when a new hearing aid is being considered, when otological examination is positive, when impedance audiometry indicates a change in the middle ear status or when teachers or parents notice a change in the child's auditory behavior.
2. Administer specific audiometric measures appropriate to the hearing-impaired child's needs and status. Children with recurring middle-ear problems may require

only pre- and post-treatment pure-tone and impedance measures. The audiologist should be prepared to administer, when indicated, such assessments as: pure-tone audiometry; carefully graded speech discrimination measures; middle-ear impedance tests; tolerance and comfortable listening levels; speechreading tests; combined modality tests; aided and unaided sound-field measures; electroacoustic analysis of hearing aids; comparative hearing-aid evaluation; comparative intelligibility functions under different degrees of filtering; binaural versus monaural evaluations; dichotic listening measures; and other psychoacoustic measures that appear appropriate; for example, synthetic formant discriminations, difference limens for frequency, intensity and time, temporal integration, and effects of masking.

3. Advise school administrators and educators regarding the selection and purchase of auditory training equipment, and further be responsible for the electroacoustic evaluation of such equipment once it is placed within the classroom. Subsequent to purchasing such equipment, conduct or provide for periodic electroacoustic evaluations of it at least once per school year.

4. Assess and monitor classroom acoustics and the proper use of amplifying equipment, with consideration of the possible effects upon speech understanding.

5. Conduct auditory training programs for individual students or groups using or developing appropriate materials for the particular children involved. The auditory training program should be based on the children's auditory status and development, and it should be developed in consultation with classroom teachers. Results of such programs should be evaluated and shared with teachers and others working with the children.

6. Participate in and/or conduct speech and language development programs based on an auditory approach.

7. Conduct inservice workshops for teachers and other staff members on such topics as microphone technique, intensity and articulation of input speech, relevance of language to topic, checking hearing aids daily, trouble-shooting of hearing aids and classroom equipment, significance of audiogram in terms of acoustics of speech, speech perception, and prosodic phenomena. Periodic classroom visits and teacher consultations may be considered inservice training too.

8. Conduct inservice training with electronics technician on the significance of the audiogram in relation to the characteristics and use of amplification equipment. Review electroacoustic data collected by the technician.

9. Make impressions for earmolds and teach earmold care to all staff members and students.

10. Participate in the admission procedures and placement procedures. Help develop criteria for early decisions regarding educational methodology to be employed with each child.

11. Participate in out-patient audiological program as appropriate in terms of community needs and time available.

12. Participate in parent-guidance and instructional counseling programs. Serve as a resource person in such programs to provide information on hearing loss, audiograms, hearing aids, acoustic environment, speech and language activities for home programs.

13. Conduct audiological research when possible and discuss its significance with staff and community leaders.

14. Evaluate quality and effectiveness of all aspects of audiology program.

Electronics Technician

1. Assess the status of hearing aids and classroom auditory training equipment at least three times during each school year.
2. Repair and maintain all auditory amplification and the speech or language training devices being used with the hearing-impaired children.
3. Assist with audiovisual equipment and videotape equipment as skills and experience permit.
4. Conduct or assist in the calibration and repair of audiometers.
5. Develop instrumentation required for research projects and programs of auditory training.

Secretary/Clerk

1. Maintain the records of the audiology program.
2. Answer telephone, make appointments, and maintain a schedule for each staff member.
3. Complete correspondence tasks required for the staff members.
4. Perform other tasks required for the operation of the audiology department under the direction of the staff members.

Audiometric Assistant

1. Perform specific tasks for which they are trained and supervised on the job by the audiologist in accordance with the American Speech and Hearing Association Guidelines on the Role, Training, and Supervision of Communication Aides adopted in November 1969 (ASHA, 1970).
2. Such tasks might include the administration of routine audiometric assessments, first echelon hearing aid maintenance, and acting as a test assistant for assessing preschool children or children who have behavior that makes them difficult to test.

Director of Audiology

1. Supervise and administer complete audiology program under the general direction of the school's chief administrator and on a coordinated basis with other department heads in the school.
2. Assign or conduct any portion of the program described above.
3. Participate in community public relations in terms of the audiology program.
4. Serve as a liaison with personnel in clinics, colleges, and universities or in the public school setting, using audiological programs. Act as audiology coordinator for any program that feeds children into the educational setting or into which children are assigned.
5. Supervise audiology practicum when school is affiliated with a college or university training program. May teach course work related to audiology services in an educational setting in the event of such an affiliation.
6. Direct or delegate research projects relative to use of amplification, effects of auditory training, and communication skills development.

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APPENDIX A

Forms used in hearing aid monitoring program (Los Angeles)

MARY E. BENNETT SCHOOL
166 South Burlington Avenue
Los Angeles, California 90057
(213) 483-3211

Celeste S. Baker
Principal

Date: _____

Dear _____,

_____ 's hearing aid was not working properly in school today.

Batteries

_____ dead, replaced, please send more to school.

_____ very weak, please check this evening.

Ear Molds

_____ need to be cleaned.

_____ fitting needs to be checked by your hearing aid dispenser (dealer) as soon as possible.

Cord

_____ broken, please replace immediately.

Hearing Aid

_____ needs to be checked by your hearing aid dispenser (dealer) as soon as possible.

Please check to see that your child's hearing aid(s) are working every morning. Thank you for your help.

Sincerely,

_____

Teacher

_____

Rosa Osuna, Audiologist

_____

Celeste S. Baker, Principal

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MARY E. BENNETT SCHOOL
166 South Burlington Avenue
Los Angeles, California 90057
(213) 483-3211

Celeste S. Baker
Principal

Fecha: _____

Estimade Sra. _____,

El audífono de _____ no estaba funcionando bien en la escuela hoy.

BATERIAS

_____Ya no sirven, fueron replazadas, por favor mande más a la escuela.

_____Muy debiles, por favor cambielas.

MOLDES DEL OIDO

_____Se necesitan limpiar.

_____El ajuste debe ser revisado por su provecdor del audífono.

CORDON

_____Se rompio, favor de reemplazarlo inmediatamente.

AUDIFONO

_____El audífono debe ser revisado por su proveedor de este aparato le mea pronto possible, no esta funcionando bien.

Por favor revise ye asegure que el audífono de su niño/a este en perfectas condiciones cada mañana. Gracias por su cooperación.

_____
Maestra

_____
Rosa Osuna, Audiologista

_____
Celeste S. Baker, Principal

MARY E. BENNETT SCHOOL
166 South Burlington Avenue
Los Angeles, California 90057
(213) 483-3211

Celeste S. Baker
Principal

Date:_____

Dear _____,

Your child, _____, was not wearing a hearing aid today. Please notify the school of its present condition. (check one)

_____ aid not working
_____ aid being repaired
_____ aid lost
_____ ear mold problems
_____ no batteries
_____ other (specify) _____

Please return this filled in form to the school. You can send it back to school with your child.

Thank you for your help.

Sincerely,

_____
Teacher

_____
Rosa Osuna, Audiologist

_____
Celeste S. Baker, Principal

File: student
audiologist

9/75 Developed by Audiologic Resource Unit, HRB

MARY E. BENNETT SCHOOL
166 South Burlington Avenue
Los Angeles, California 90057
(213) 483-3211

Celeste S. Baker
Principal

Fecha: _____

Estimade Sra. _____,

_____ llegó hoy a la escuela sin su audífono puesto.
Por favor indique en esta forma por que no lo trajo.

_____
Maestra

_____
Rosa Osuna, Audiologista

_____
Celeste S. Baker, Principal

_____ Lo estan companiendo
_____ No trabaja
_____ Lo perdió
_____ Noy hay baterías
_____ Problemas con el molde
_____ Otra cosa (especifique)_____

Comentarios:

_____
Firma del padre e guardian

File: student
audiologist

FOR TEACHERS:

HOW TO GIVE A LISTENING CHECK TO THE CHILD'S PERSONAL HEARING AID

1. Use your own individual ear mold if you have one.
2. Check the battery to see that it is in correctly, clean battery terminals with an eraser if necessary. In ear level aids, terminals should be cleaned by dealer.
3. Establish a comfortable listening level for each hearing aid and listen daily at this volume setting. If the aid sounds weak, insert a new battery if one is available. If volume is still low, refer parent to dispenser.
4. Set controls:
   A. "On/Off" switch in "Off" position.
   B. Volume Control at lowest setting.
   C. Switch in "M" or mike position.
   D. Tone control in setting most frequently needed.
5. Place the receiver to your ear. Cover the receiver with the palm of your hand and hold the main part of the hearing aid away from your ear to prevent feedback.
6. Turn the hearing aid "On." Turn the volume control wheel up and down, slowly, listening for scratchiness or dead spots. The volume control should neither be excessively loose, nor bind against the case.
7. Turn the "On/Off" switch back and forth to check for intermittent sound or loose contacts.
8. Establish a comfortable listening level.
9. Roll the cord back and forth between the fingers to check for "cut-cuts" with body aid. With ear level aids, check the plastic tubing for possible stiffness, pinholes, or cracks.
10. Check the firmness of cord connections.
11. Gently tap the hearing aid on all sides to check for a reduction of power or loose connections. Check for loose screws in the case.
12. With the aid in the "Off" position and the receiver out of your ear, place your thumb firmly over the opening in the receiver. Turn the hearing aid on and turn the volume all the way up. Listen for a soft whistling sound from the hearing aid case or from the receiver. With ear level aids, put your thumb firmly over the opening in the ear mold.
13. Check the earmold for cleanliness. Clean if necessary. Suggested, that a weekly classroom project involve cleaning ear molds. In this way the children can learn how to take care of their molds and transfer this knowledge to their home. Pick one time a week to thoroughly clean the molds by soaking them in warm soapy water for about five minutes. Rinse them with clear water and let them dry on a paper towel until all the water is out of the canal. A pipecleaner can be used to dry and to clean the bore of the mold. Do not use the mold until it is completely dry.
14. Use the letter to parent re: pupils personal hearing aid forms (PHA—1 to 3).

APPENDIX B

Release forms distributed to parents
of hearing-impaired children

AUDIOLOGIC RESOURCE UNIT
SUMMARY OF AMPLIFICATION MONITORING FORMS

School _____ Student _____

Teacher _____ Year _____

MONTHS	HEARING AID	RIGHT EAR ( ) LEFT EAR ( )	AID UNSATISFACTORY	AID NOT FUNCTIONING	FEEDBACK	POWER SWITCH	GAIN CONTROL	CORD	EAR MOLD	RECEIVER	A.T.U. ( ) E.F.Y. ( ) OR OTHER ( )	NOT FUNCTIONING OR UNSATISFACTORY	HEAD SET ( ) EAR MOLD ( )	STRAPS, SNAPS, ETC.	OTHER	ACTION/COMMENTS
SEPT																
OCT																
NOV																
DEC																
JAN																
FEB																
MAR																
APR																
MAY																
JUN																
SUM																

Summary Statement: _____

_____

_____

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AUDIOLOGIC RESOURCE UNIT
AMPLIFICATION MONITORING FORM

School _____ Student _____

Teacher _____ Month _____ Year _____

DATE	HEARING AID	RIGHT EAR ( ) LEFT EAR ( )	AID UNSATISFACTORY	AID NOT FUNCTIONING	FEEDBACK	BATTERY	POWER SWITCH	GAIN CONTROL	CORD	RECEIVER	EAR MOLD	A.T.U. ( ) E.F.I. ( ) OTHER ( )	SATISFACTORY	UNSATISFACTORY	NOT FUNCTIONING	READ SET ( ) EAR MOLD ( )	STRAPS, SNAPS, ETC.	OTHER	EXPLANATION

To the Parent or Guardian of_____

From: The Los Angeles City Unified School District

In cooperation with the Bureau of Education for the Handicapped, U.S. Office of Education, the Los Angeles City Unified School District is examining the working condition of hearing aids.

This study assumes that your child is wearing the correct aid; therefore its purpose is to test to find out if your child's hearing aid is working technically as stated in the manufacturer's specification. You will be informed of the results of the test of your child's aid. The test will be done at your child's school. It will take 15 to 30 minutes. Your child's audiological records will be examined to check against the current working of his or her aid. There will be no charge for testing your child's hearing aid.

There will be no identification in the data of your child, no demographic information, and no examination of your child's academic, psychological or counseling records will be made. Your child will not be asked any questions except those specific to the technical examination of his or her aid.

A small number of aids will be selected at random to be given a more rigorous laboratory examination. The study will assume the responsibility for the aid when it is sent to the laboratory. While your child's aid is at the laboratory he or she will be provided a loaner aid at no risk to you. Your child's own aid will be returned within 10 to 14 days.

Thank you for your cooperation.

I give my permission for my child to participate in this study.

Signed: _____

Date: _____

Para los Padres o el Guardián de _____

DE: El Distrito Escolar Unificado de la Ciudad de Los Angeles

En cooperación con la Agencia de Educación para los Incapacitados, Oficina Federal de Educación, el Distrito Escolar Unificado de la Ciudad de Los Angeles esta examinando la condición del funcionamiento de los audífonos.

Esta encuesta asume que su niño está usando el aparato apropiado; por esta razón el propósito de dicha encuesta es el de conducir pruebas para determinar si el audífino usado por su niño funciona técnicamente tal como lo dictan las especificaciones del fabricante. Se le informará a Ud. sobre los resultados obtenidos acerca de las pruebas del audífono de su niño. Los pruebas tendrán iugar en las escuela a la que su niño asiste. Tomará de 15 a 30 minutos. Los registros audiológicos de su niño seran examinados para compararlos con el funcionamiento actual del audífon.

No habrá identificación en los datos acerca de su niño, ni habrá información demográfica y tampoco se condducirá ninguna examinación de los registros académicos, psicológicos o de asesoramiento del mismo. No se le harán a su niño ningunas preguntas excepto aquellas que sean especificas para la examinación técnica de dicho aparato.

Se seleccionarán al azar un número pequeño de audífonos para someterlos a una examinación de laboratorio más rigorosa. La encuesta asumirá responsabilidad por el aparato al ser enviado éste al laboratorio. Mientras el audífono de su niño está en el laboratorio él o ella será provisto (a) de un aparato prestado sin riesgo alguna para Ud. El audífono de su niño será regresado en un período de 10 a 14 dias. Gracias de antemano por su cooperación.

Doy mi permiso para que mi niño participe en esta encuesta.

Firma: _____
Fecha: _____
Escuela: _____

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